THE DESIGN OF ROTATING DISCS.

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THE complete evaluation of the stresses in a rotating disc is of necessity a somewhat tedious process; but in view of the present-day tendency towards turbine units of large cutput running at relatively high speeds of rotation, it is a problem which has carefully to be considered. Since the grade of steel commercially obtainable for the manufacture of discs has a fairly definite maximum tensile strength it is essential that we so proportion our discs that the disposition of stresses is such as to give the highest possible factor of safety consistent with the qualities of material that are procurable.

Definite solutions of the differential equations of stress have only been obtained for a few particular cases where the radius and the axial thickness of a disc bear a definite mathematical relationship. Thus Professor Stodola obtained a solution for the case of discs of hyperbolic section :—

Where x = any radius of disc.
y = corresponding thickness.
Then :

$$y\,x^a = \text{Constant}.$$

Mr. H. M. Martin showed that for discs of the above type it is possible to construct a series of standard curves corresponding to various values of a, and by the use of these the amount of work involved was greatly reduced. Both of these methods were, however, only applicable to discs whose profile conformed throughout to the hyperbolic law. In actual practice it is in many cases impracticable to employ discs which conform even approximately to this contour, and a further point of even greater importance is that a disc of hyperbolic form does not in many cases produce the best distribution of stresses.

In the method here outlined the mathematical accuracy of the original solution of Stodola has been maintained, but the equations have been so transposed that discs of any reasonable contour can be treated. Fig. 1 shows the practical design of a simple turbine disc, the sides having straight line tapers. If this disc be now considered to consist of a series of consecutive rings, 1. 2. 3. &c., although the complete disc by no means conforms to a true hyperbolic section, by making the radial steps of moderate dimensions, the error involved in assuming any particular section to form a portion of an "a" disc is negligible. Thus in Fig. 1 the various sections indicated have a values as follows :—

Section	1	2	3	4	5	6	7	8
a =	0·62	0·91	1·27	1·6	0·52	0·72	1·0	1·44

The method adopted consists of a simple means of co-ordinating the various sections and so obtaining a complete solution of the disc. Further it will be shown that it is possible to reverse the process and that after drawing down a stress curve to suit any particular requirements the disc shape necessary to meet the case can be obtained.

The distribution of stresses in a disc of hyperbolic section is given by the following equations :—

$$\sigma_r = \frac{E}{1-\nu^2}\left[\beta_1(\psi_1+\nu)x^{\psi_1-1} + \beta_2(\psi_2+\nu)x^{\psi_2-1} - \frac{K(3+\nu)}{[8-(3+\nu)a]}x^2\right] \quad . \quad . \quad \text{(i)}$$

$$\sigma_t = \frac{E}{1-\nu^2}\left[\beta_1(1+\psi_1\nu)x^{\psi_1-1} + \beta_2(1+\psi_2\nu)x^{\psi_2-1} - \frac{K(1+3\nu)}{[8-(3+\nu)a]}x^2\right] \quad . \quad \text{(ii)}$$

$$\psi_1 = \frac{a}{2} + \sqrt{\frac{a^2}{4} + a\nu + 1}$$

$$\psi_2 = \frac{a}{2} - \sqrt{\frac{a^2}{4} + a\nu + 1}$$

σ_r = Radial Stress.
σ_t = Tangential stress.
E = Elastic modulus.
ν = Poisson's ratio (0·3 for steel).
x = Radius in inches.

$$K = \frac{w\,\omega^2}{12\,g} = 8{\cdot}05\left(\frac{R\,P\,M}{1{,}000}\right)^2 \text{ for steel discs.}$$

(It is to be noted that $K\,x^2$ gives the hoop stress in an unsupported steel ring of radius x.)

β_1 and β_2 are constants which depend upon the conditions of loading at the inner and outer edges of the disc.

If we write in equations (i) and (ii) arbitrary values σ_{r_0} and σ_{t_0} at any definite radius x_0, the values of β_1 and β_2 can at once be determined, and corresponding stress at any other radius x can then be found.* Adopting this procedure, equations (i) and (ii) can then be thrown into the simple forms :—

$$\sigma_r = A\,\sigma_{r_0} + B\,\sigma_{t_0} - C\,K\,x_0^2 \quad . \quad . \quad \text{(iii)}$$

$$\sigma_t = E\,\sigma_{r_0} + F\,\sigma_{t_0} - G\,K\,x_0^2 \quad . \quad . \quad \text{(iv)}$$

From these equations it will be seen that at any point both the radial and tangential stresses comprise a definite proportion of the radial and tangential stresses at the known point, less a factor depending upon the hoop stress due to the running speed. If we put $r = \frac{x}{x_0}$, then the values of the various constants are as follows :—

$$A = \frac{\psi_1 r^{\psi_1-1} - \psi_2 r^{\psi_2-1}}{\psi_1 - \psi_2}$$

$$B = \frac{r^{\psi_1-1} - r^{\psi_2-1}}{\psi_1 - \psi_2}$$

$$C = \frac{\left\{(3+\nu)(\psi_1-\psi_2)r^2 - (\psi_1+\nu)(3-\psi_2)r^{\psi_1-1} + (\psi_2+\nu)(3-\psi_1)r^{\psi_2-1}\right\}}{(\psi_1-\psi_2)[8-(3+\nu)a]}$$

$$E = \frac{(1+a\nu)\left(r^{\psi_1-1} - r^{\psi_2-1}\right)}{\psi_1-\psi_2}$$

$$F = \frac{\psi_1 r^{\psi_2-1} - \psi_2 r^{\psi_1-1}}{\psi_1-\psi_2}$$

$$G = \frac{\left\{(1+3\nu)(\psi_1-\psi_2)r^2 - (1+\nu\psi_1)(3-\psi_2)r^{\psi_1-1} + (1+\nu\psi_2)(3-\psi_1)r^{\psi_2-1}\right\}}{(\psi_1-\psi_2)[8-(3+\nu)a]}$$

* The insertion of arbitrary stresses in Stodola's equations appears to have been first suggested by H. Holzer, *Zeitschrift Turbinenwesen*, September 20, 1913.

In the expressions for A, B, C, E, F and G there are two variables, r and a, and the constants have been evaluated for values of a varying from 0 to 3, and values of r from 1·2 to 1·02. These results are given in Tables I, II, III and IV, on page 418, but as in dealing with actual examples it is much simpler to base the calculations on the ratio $\frac{y_0}{y} = r^a = \rho$ the final results given in the tables are shown as corresponding to definite values of ρ.

In calculating the stresses of any given disc it is most convenient to commence at the bore of the hub and to work outwards, since at this point the radial stress may be taken as zero. Even in the case of a disc shrunk on to the shaft, when the disc is brought up to speed, the effect of the shrinkage practically disappears.

For most cases we may employ Table I, where the ratio of succeeding steps is 1·2, commencing at the inner radius a series of radial dimensions are written down, each having a uniform increment of 20 per cent. The spacing of the steps is thus a simple geometric progression, the distance between successive steps being proportional to their distance from the centre of the disc. This spacing is quite satisfactory, since it gives the closest pitching at the points where the stress curves have their steepest gradients. Having ascertained the radial steps the corresponding disc thicknesses can be written down, and thence the ratio $\frac{y_0}{y} = \rho$ for each step. It is now only necessary to read from Table I the constants corresponding to the required values of ρ.

As an example, the maximum load-carrying capacity of the disc shown in Fig. 2 has been calculated for a speed of 3,000 r.p.m. The whole of the working is given in Table V. The explanation of the various columns is as follows :—

(1) The radius at which the stress is required.

(2) The ratio of succeeding radii, in this case taken as 1·2, except at the last step where $r = 1{\cdot}02$, was taken to bring the value of x to the outside radius of 22 in.

(3) The thickness taken from the disc to correspond to radius x.

(4) The ratio ρ for succeeding values of y.

(5) The value of $K\,x_0^2$ required in columns 7 and 10. In this case for a speed of 3,000 r.p.m.

$$K = 8{\cdot}05\left(\frac{3{,}000}{1{,}000}\right)^2 = 72{\cdot}45.$$

The suffix o in each case indicates the value from the preceding step so that at $x = 6$, $K\,x_0^2 = 72{\cdot}45 \times 5^2 = 1{,}810$.

(6) Constants taken from table corresponding to the correct value of r and ρ.

(7) The three factors in equation (iii).

(8) The sum of the factors giving the radial stress at the new radius.

(9) Constants from tables.

(10) The three factors in equation (iv).

(11) The sum of these factors giving the new tangential stress.

The values in columns 1, 2, 3 4, and 5 can be filled in completely, from the particulars of the disc. If now we decide upon a maximum tangential stress of 28,000 lb. per square inch at the bore of the disc ($x = 5$ in.), this is filled in on the first line, the corresponding radial stress being zero. Using these values the stresses at the next step can be found, and repeating the process throughout the disc the complete solution is obtained. The stress curves are shown plotted in Fig. 2. It will be seen that at the disc periphery a radial stress of 12,090 lb. per square inch is obtained, and providing the loading of the disc due to the centrifugal force of blading and disc rim does not exceed this figure, we know that the maximum disc stress at the bore is within the safe limit of 28,000 lb. per square inch. This in most cases is all that is necessary, but if the exact stress curves are required to correspond to some other radial rim stress, these can readily be obtained by adopting the principle set out by Mr. Martin in connection with his standard disc curves. He shows that in any disc it is possible to divide the stress at any point into two portions (1) that due to the centrifugal force acting on the disc itself and (2) the stress induced due to the applied centrifugal loading at the rim.

These stresses can be calculated separately, the

Fig. 1.

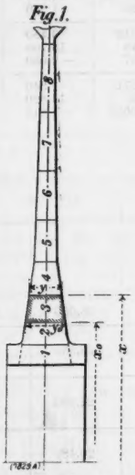

Fig. 2.

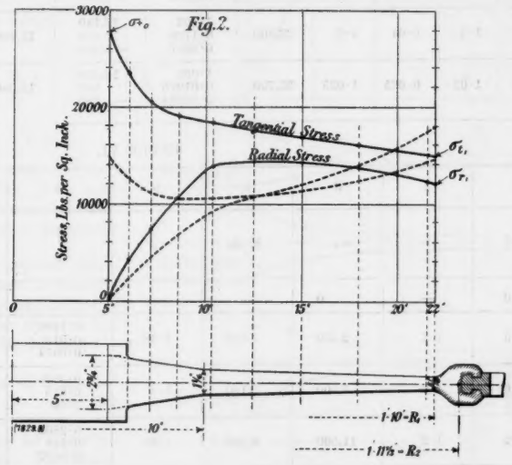

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Table I.—*Values of Constants for* $r = 1 \cdot 2$.

ρ.	A.	B.	C.	E.	F.	G.
1·0	0·848	0·1520	0·2090	0·1520	0·848	0·0780
1·02	0·865	0·1535	0·2108	0·1580		0·0786
1·04	0·882	0·1549	0·2126	0·1652		0·0792
1·06	0·889	0·1564	0·2143	0·1718		0·0798
1·08	0·916	0·1578	0·2161	0·1784		0·0804
1·1	0·933	0·1593	0·2179	0·1850	0·848	0·0810
1·12	0·950	0·1608	0·2197	0·1917		0·0816
1·14	0·967	0·1622	0·2215	0·1983		0·0822
1·16	0·984	0·1637	0·2232	0·2049		0·0828
1·18	1·001	0·1651	0·2250	0·2115		0·0834
1·2	1·018	0·1666	0·2268	0·2182	0·848	0·0840
1·22	1·035	0·1681	0·2286	0·2248		0·0846
1·24	1·052	0·1695	0·2304	0·2314		0·0852
1·26	1·069	0·1710	0·2321	0·2380		0·0858
1·28	1·086	0·1724	0·2339	0·2446		0·0864
1·3	1·103	0·1739	0·2357	0·2513	0·848	0·0870
1·32	1·120	0·1754	0·2375	0·2579		0·0876
1·34	1·137	0·1768	0·2393	0·2645		0·0882
1·36	1·153	0·1783	0·2410	0·2711		0·0888
1·38	1·170	0·1797	0·2428	0·2777		0·0894
1·4	1·117	0·1812	0·2446	0·2845	0·848	0·0900
1·42	1·204	0·1827	0·2464	0·2911		0·0906
1·44	1·221	0·1841	0·2482	0·2977		0·0912
1·46	1·238	0·1856	0·2499	0·3043		0·0918
1·48	1·255	0·1870	0·2517	0·3114		0·0924
1·5	1·272	0·1885	0·2535	0·3180	0·848	0·0930
1·52	1·289	0·1900	0·2553	0·3246		0·0936
1·54	1·306	0·1914	0·2571	0·3312		0·0942
1·56	1·323	0·1929	0·2588	0·3378		0·0948
1·58	1·340	0·1943	0·2606	0·3444		0·0954
1·6	1·357	0·1958	0·2624	0·3510	0·848	0·0960
1·62	1·374	0·1973	0·2642	0·3576		0·0966
1·64	1·391	0·1987	0·2660	0·3642		0·0972
1·66	1·408	0·2002	0·2677	0·3708		0·0978
1·68	1·425	0·2016	0·2695	0·3774		0·0984
1·7	1·442	0·2031	0·2713	0·3840	0·848	0·0990

Table II.—*Values of Constants for* $r = 1 \cdot 1$.

ρ.	A.	B.	C.	E.	F.	G.
1·0	0·913	0·0870	0·1020	0·0870	0·913	0·0347
1·01	0·922	0·0874	0·1025	0·0902		0·0348
1·02	0·931	0·0879	0·1029	0·0934		0·0350
1·03	0·940	0·0883	0·1034	0·0966		0·0352
1·04	0·949	0·0887	0·1039	0·0998		0·0353
1·05	0·959	0·0892	0·1044	0·1025	0·913	0·0355
1·06	0·968	0·0896	0·1048	0·1062		0·0356
1·07	0·977	0·0900	0·1053	0·1094		0·0358
1·08	0·986	0·0904	0·1058	0·1123		0·0359
1·09	0·995	0·0909	0·1062	0·1157		0·0361
1·1	1·004	0·0913	0·1067	0·1190	0·913	0·0362
1·11	1·014	0·0917	0·1072	0·1222		0·0364
1·12	1·023	0·0922	0·1077	0·1254		0·0365
1·13	1·032	0·0926	0·1081	0·1286		0·0367
1·14	1·041	0·0930	0·1086	0·1318		0·0368
1·15	1·050	0·0934	0·1090	0·1350	0·913	0·0370
1·16	1·059	0·0939	0·1095	0·1382		0·0371
1·17	1·068	0·0943	0·1100	0·1414		0·0373
1·18	1·077	0·0947	0·1104	0·1446		0·0374
1·19	1·086	0·0952	0·1109	0·1478		0·0376
1·2	1·096	0·0956	0·1114	0·1510	0·913	0·0378
1·21	1·105	0·0960	0·1119	0·1542		0·0379
1·22	1·114	0·0965	0·1123	0·1574		0·0381
1·23	1·123	0·0969	0·1128	0·1606		0·0382
1·24	1·132	0·0973	0·1132	0·1638		0·0384
1·25	1·142	0·0978	0·1137	0·1670	0·913	0·0385
1·26	1·151	0·0982	0·1142	0·1702		0·0387
1·27	1·160	0·0987	0·1147	0·1734		0·0388
1·28	1·169	0·0991	0·1152	0·1766		0·0390
1·29	1·178	0·0995	0·1156	0·1792		0·0391
1·3	1·188	0·0999	0·1161	0·1824	0·913	0·0393
1·31	1·197	0·1004	0·1166	0·1856		0·0394
1·32	1·206	0·1008	0·1171	0·1888		0·0396
1·33	1·215	0·1012	0·1175	0·1920		0·0398
1·34	1·224	0·1017	0·1180	0·1952		0·0399
1·35	1·234	0·1021	0·1185	0·1984	0·913	0·0401

Table III.—*Values of Constants for* $r = 1 \cdot 05$

ρ.	A.	B.	C.	E.	F.	G.
1·0	0·953	0·0465	0·0505	0·0465	0·953	0·01620
1·01	0·963	0·0467	0·0507	0·0496		0·01628
1·02	0·973	0·0469	0·0510	0·0527		0·01636
1·03	0·982	0·0472	0·0512	0·0558		0·01644
1·04	0·992	0·0474	0·0515	0·0589		0·01652
1·05	1·001	0·0477	0·0517	0·0620	0·953	0·01659
1·06	1·011	0·0479	0·0520	0·0651		0·01667
1·07	1·020	0·0481	0·0522	0·0682		0·01675
1·08	1·029	0·0484	0·0524	0·0713		0·01683
1·09	1·039	0·0486	0·0527	0·0744		0·01691
1·1	1·048	0·0488	0·0529	0·0775	0·953	0·01699
1·11	1·058	0·0491	0·0531	0·0806		0·01706
1·12	1·067	0·0493	0·0534	0·0837		0·01714
1·13	1·077	0·0495	0·0536	0·0868		0·01722
1·14	1·086	0·0498	0·0538	0·0899		0·01730
1·15	1·096	0·0500	0·0541	0·0930	0·953	0·01738

TABLE V.

1	2	3	4	5	6	7	8	9	10	11
x		y	ρ	$K x^2_0$	A B C	$A\sigma_{r_0}$ $B\sigma_{t_0}$ $-CKx^2_0$	σ_r	E F G	$E\sigma_{r_0}$ $F\sigma_{t_0}$ $-GKx^2_0$	σ_t
5·0	—	2·75	—	—	—	—	0	—	—	28,000
6·0	1·2	2·44	1·12	1,810	0·950 0·1608 0·2197	0 4,500 − 390	4,110	0·1917 0·848 0·0816	0 23,800 − 150	23,650
7·2	1·2	2·08	1·18	2,600	1·001 0·1651 0·2250	4,110 3,900 − 580	7,430	0·2115 0·848 0·0834	870 20,050 − 220	20,700
8·64	1·2	1·65	1·26	3,740	1·069 0·1710 0·2321	7,950 3,540 − 870	10,620	0·2380 0·848 0·0858	1,770 17,600 − 320	19,050
10·4	1·2	1·23	1·34	5,370	1·137 0·1768 0·2393	12,070 3,370 − 1,290	14,150	0·2645 0·848 0·0882	2,810 16,170 − 480	18,500
12·5	1·2	1·12	1·1	7,850	0·933 0·1593 0·2179	13,200 2,950 − 1,700	14,450	0·1850 0·848 0·0810	2,620 15,700 − 630	17,690
15·0	1·2	0·99	1·14	11,200	0·967 0·1622 0·2215	13,960 2,870 − 2,500	14,330	0·1983 0·848 0·0822	2,870 15,000 − 930	16,940
18·0	1·2	0·83	1·2	16,200	1·018 0·1666 0·2268	14,600 2,820 − 3,680	13,740	0·2182 0·848 0·084	3,120 14,380 − 1,360	16,140
21·6	1·2	0·64	1·3	23,300	1·103 0·1739 0·2357	15,140 2,810 − 5,540	12,410	0·2513 0·848 0·087	3,450 13,700 − 2,030	15,120
22·0	1·02	0·625	1·025	33,700	1·005 0·01975 0·02024	12,470 300 − 680	12,090	0·0271 0·98 0·00622	340 14,820 − 210	14,950

TABLE VI.

1	2	3	4	5	6	7	8	9
x	r	σ_r	$K x^2_0$	ρ	E F G	$E\sigma_{r_0}$ $F\sigma_{t_0}$ $-GKx^2_0$	σ_t	y
5·0	—	0	—	—	—	—	28,000	3·9
5·5	1·1	2,450	1,810	1·18	0·1446 0·913 0·0374	0 25,600 − 70	25,530	3·3
6·6	1·2	7,000	2,180	1·4	0·2845 0·848 0·09	700 21,700 − 200	22,200	2·35
7·92	1·2	11,500	3,150	1·39	0·2806 0·848 0·0897	1,960 18,800 − 280	20,480	1·69
9·5	1·2	16,000	4,520	1·38	0·2777 0·848 0·0894	3,200 17,400 − 400	20,200	1·225
11·4	1·2	19,800	6,500	1·31	0·2545 0·848 0·0873	4,070 17,100 − 570	20,600	1·01
13·7	1·2	21,000	9,400	1·18	0·2115 0·848 0·0834	4,180 17,500 − 780	20,900	0·857
16·4	1·2	21,000	13,500	1·16	0·2049 0·848 0·0828	4,330 17,700 − 1,120	20,910	0·738
19·75	1·2	21,000	19,400	1·23	0·2281 0·848 0·0849	4,850 17,700 − 1,640	20,910	0·6

Table IV.—*Values of Constants for* $r = 1 \cdot 02$.

ρ.	A.	B.	C.	E.	F.	G.
1·0	0·980	0·01950	0·02000	0·0195	0·980	0·00615
1·005	0·985	0·01955	0·02005	0·0210		0·00616
1·01	0·990	0·01960	0·02010	0·0225		0·00618
1·015	0·995	0·01965	0·02015	0·0240		0·00619
1·02	1·000	0·01970	0·02019	0·0256		0·00621
1·025	1·005	0·01975	0·02024	0·0271		0·00622
1·03	1·010	0·01980	0·02029	0·0286		0·00624
1·035	1·015	0·01985	0·02034	0·0301		0·00625
1·04	1·020	0·01990	0·02038	0·0317		0·00627
1·045	1·025	0·01995	0·02043	0·0332		0·00628
1·05	1·030	0·02000	0·02048	0·0347		0·00630
1·055	1·035	0·02005	0·02053	0·0362		0·00631
1·06	1·040	0·02010	0·02059	0·0378		0·00633

results being added together to obtain the final stress curve. Referring back to equations (iii) and (iv), if we assume that the speed of rotation is zero, the value of K becomes 0 and the last term disappears. All effect of centrifugal force on the disc itself is now eliminated, and stress curves obtained represent induced stresses due to the application of a load at the rim. The dotted curves in Fig. 2 show the values obtained by assuming under these conditions a stress of 15,000 lb. per square inch at the hub. It will be seen that the corresponding radial stress at rim is 18,100 lb. per square inch.

We can now write for the total tangential stress at hub:

$$\sigma_{t_0} = P + Q\,\sigma_{r_1}$$

Where

P = Tangential stress due to disc itself.
Q = Ratio of induced tangential stress at hub to radial stress at rim.

$$= \text{in this case } \frac{15{,}000}{18{,}100} = 0 \cdot 83$$

From the original solution we thus have:

$$28{,}000 = P + 0 \cdot 83 \times 12{,}090$$
$$P = 18{,}000$$

And thus

$$\sigma_{t_2} = 18{,}000 + 0{\cdot}83\,\sigma_{r_1}$$

from which the maximum stress corresponding to any desired radial load at rim can be obtained. This same simple method of proportion can be adopted to find radial or tangential stresses at any other point of the disc.

The Effect of a Heavy Rim.—As the heavy rim of the disc will have under running conditions a tangential stress, it will be to a certain extent self-supporting, and consequently the load which the disc has to carry comprises only a certain proportion of the load due to the weight of the rim, together with the extra load due to the centrifugal pull of the blading.

Let the cross-sectional area of the rim be A sq. in., with its centre of gravity at a radius R_2 and the centrifugal load due to the blading be L lb. It is sufficiently accurate to assume that an average tangential stress of σ_{t_2} exists over the whole of the rim area. This stress is produced by three factors :—

(Blade load L) + (Unsupported hoop stress $K R_2^2$) − (Supporting load due to radial stress at R_1)

Thus

$$\sigma_{t_2} = \frac{L}{2\pi A} + K R_2^2 - \frac{\sigma_{r_1} R_1 y_1}{A}$$

At the point where the rim joins the disc the radial strains must be equal, so we have :

$$\frac{R_1}{E}(\sigma_{t_1} - \nu\sigma_{r_1}) = \frac{R_1}{E}\sigma_{t_2}$$

(The average radial stress in the rim being so small that it can be neglected).

Whence :

$$\sigma_{t_1} - \nu\sigma_{r_1} = \frac{L}{2\pi A} + K R_2^2 - \frac{\sigma_{r_1} R_1 y_1}{A}$$

and

$$L = 2\pi A\left[\sigma_{t_1} + \sigma_{r_1}\left(\frac{R_1 y_1}{A} - \nu\right) - K R_2^2\right]$$

In the disc shown in Fig. 2 the area of rim is 2·2 sq. in. and $R_2 = 23{\cdot}5$ in. This gives from above equation L = 650,000 lb. as the actual blade loading which the disc will stand at a maximum stress of 28,000 lb. per square inch.

The Design of Discs to Suit Definite Stress Requirements. — In many cases where a heavily-loaded disc is required it is more convenient firstly to decide upon the disposition of the stresses and then to calculate the necessary profile to suit the case.

Before indicating how the method of treatment already described can be applied to meet this reversed system of calculation, it is necessary to consider the limitations which must be observed when fixing arbitrarily the stresses. The inter-relationship of the radial and tangential stresses in any disc is expressed by the following differential equation :

$$\frac{d\sigma_t}{dx} + (1+\nu)\frac{\sigma_t}{x} = \nu\frac{d\sigma_r}{dx} + (1+\nu)\frac{\sigma_r}{x} \quad . \quad (v)$$

It will be noted that this expression merely shows the relationship between the two series of stresses, this relationship existing irrespective of the speed at which the disc is running, or of the disc thicknesses, since terms involving these two factors do not enter into the equation. If now we fix arbitrarily a curve for, say, the radial stresses of a disc, the terms on the right-hand side of the equation are fully established for all points on the disc. It then becomes only possible to settle arbitrarily one point on the corresponding tangential stress curve, when all the remaining points are automatically fixed by the requirements of equation (v).

Thus, as example, Fig. 3 shows the radial stress curve R R required in a disc of 39½ in. outside diameter. If a stress of 28,000 lb. per square inch be decided upon as the maximum tangential stress at the bore, the corresponding tangential stress curve corresponding to equation (v) is shown at T T, and no matter at what speed the disc is running this is the only tangential stress curve which can exist in conjunction with the radial stress curve R R.

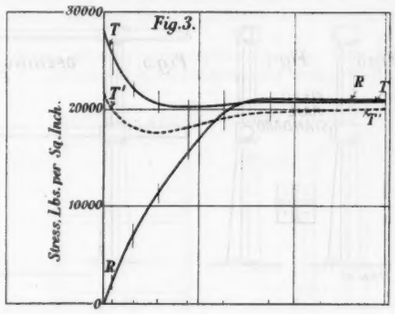
Below the curves are shown the corresponding disc profiles to meet the stress requirements at speeds of 2,400 r.p.m., 3,000 r.p.m. and 3,600 r.p.m. respectively. Had the maximum tangential stress been fixed at a lower value of 22,000 lb. per square inch the tangential stress curve would have taken the form shown by the dotted curve T′ T′, and the disc thicknesses would have been increased.

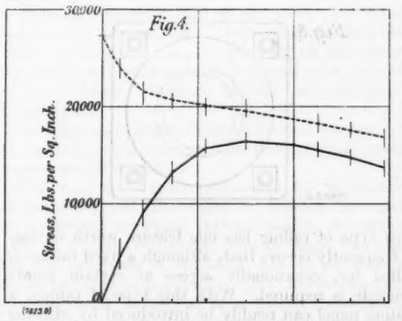
Referring back to equation (iii) the values of the constants A, B and C have been found to bear a straight line relationship to ρ, thus :

$$A = a\,\rho$$
$$B = b_1 + b_2\,\rho$$
$$C = c_1 + c_2\,\rho.$$

It must be understood that these straight line relationships are purely impirical, but nevertheless they hold good with considerable accuracy over the range of values of r and ρ given in Tables I and IV. The values of the new constants a, b_1, b_2, c_1 and c_2 vary for different values of r as follows :—

r =	1·02	1·05	1·1	1·2
a =	0·9805	0·9535	0·913	0·848
b_1 =	0·0095	0·0231	0·044	0·079
b_2 =	0·01	0·0234	0·043	0·073
c_1 =	0·0105	0·0235	0·055	0·12
c_2 =	0·0095	0·024	0·047	0·089





Inserting these values in equation (iii) we obtain :—

$$\rho = \frac{\sigma_r - b_1\sigma_{t_0} + c_1 K x_0^2}{a\,\sigma_{r_0} + b_2\,\sigma_{t_0} - c_2\,K x_0^3}$$

This expression gives the ratio of disc thicknesses for any step providing the radial stress curve is known and also the tangential stress at the inner edge of the step.

As an example of the application of this method Table VI gives the calculation of the disc profile to suit the stress curves in Fig. 3 at a speed of 3,000 r.p.m. It will be noted that after obtaining the value of ρ in column 5, the constants E, F and G can be taken from the tables and the value of σ_t calculated. This new value of σ_t is then employed to obtain ρ for the next step. Finally having evaluated ρ for each step of the disc, the thickness at outer edge being determined by the load to be supported, the thicknesses at all other points are at once obtainable.

In this particular case a thickness of 0·6 in. is required at the rim, thus thickness at 16·4 in. radius is $0{\cdot}6 \times 1{\cdot}23 = 0{\cdot}738$ in., at 13·7 is $0{\cdot}738 \times 1{\cdot}16 = 0{\cdot}857$ in., and so on.

A simple approximate check on stress curves obtained by the above method is possible by assuming in equation (v) that between any two steps the radial stress follows the straight line $\sigma_r = m + n\,x$.

Inserting this value in equation (v) :

$$\frac{d\sigma_t}{dx} + (1+\nu)\frac{\sigma_t}{x} = (1+\nu)\frac{m}{x} + (1+2\nu)\,n$$

Whence :

$$\sigma_t = m + \left(\frac{1+2\nu}{2+\nu}\right)n\,x + \frac{\text{constant}}{x^{1+\nu}}$$

For values of

$$r = \frac{x}{x_0} = 1{\cdot}2$$

this gives

$$\sigma_t = 0{\cdot}37\,\sigma_r - 0{\cdot}16\,\sigma_{r_0} + 0{\cdot}79\,\sigma_{t_0} \quad . \quad (vi)$$

And for $r = 1{\cdot}1$:

$$\sigma_t = 0{\cdot}35\,\sigma_r - 0{\cdot}23\,\sigma_{r_0} + 0{\cdot}88\,\sigma_{t_0} \quad . \quad (vii)$$

These expressions enable the approximate tangential stress curve to be found to correspond to any given radial stress curve. The assumption of a straight-line law for the radial stress of each step leads to a slightly disjointed curve, as shown in Fig. 4, but careful investigation shows that this only involves very slight errors, and consequently it is quite permissible for checking purposes to utilise equations (vi) or (vii) in conjunction with points read from a smooth radial stress curve.

QUAYSIDE EQUIPMENT.

By ERNEST LATHAM, M.Inst.C.E.

THE building of docks, harbours, quays and jetties is always an expensive undertaking, the costs varying naturally with the conditions of each site. The involved questions of foundations, earth pressures, excavations, pile driving, and a host of other specialised questions call for much time and study from the engineer responsible for the execution of such works. It is perhaps for this reason that engineers are liable to overlook those other matters which, not involving expense on the same scale, nevertheless have considerable bearing on the efficient working of any quay.

Omitting the important subjects of cargo-handling and the design of suitable staithes, tips, cranes and transporters, we are left with the apparently prosaic study of such minor matters as bollards, ladders, capstans, &c. It must, however, be borne in mind that the proper berthing of any ship is a matter of first importance. The correct position of the bollards that receive the "spring" ropes of a ship, for example, is important; bollards must permit of sufficient surface contact to prevent ropes "rendering" round them, and nothing must be designed or placed on the quayside to cause the chafing of ropes. On the other hand, the structure itself must be protected from the attrition of steel hawsers or wire ropes cutting through kerbs or through timber bollard piles or from possibly wearing away the protective skin of concrete in the case of quays constructed in reinforced concrete. These are but a very few of the so-called minor questions which, none the less, have a vital bearing on efficient design.

On the completion of any marine undertaking of importance it is always open to the criticism of the Dock Company or authority for whom it has been constructed or to the natural comments of a private wharfinger, as the case may be. Many real structural defects may never be detected, and little appreciation may be expressed for the way in which the engineer has met and successfully overcome grave submarine difficulties. It is the relatively small matters which invariably will be examined in detail, such as the position of the boat steps, the accessibility of ladders, the lay-out of railway tracks, the type of stanchions or the suitability of the fendering as designed.

Now it will be evident that, as physical conditions and difficulties in regard to the main structure vary with the site, so also do the requirements in the design of quayside accessories vary with the class and size of shipping to berth alongside. In the Oil Trade, for example, where tank steamers of 20,000 tons burthen are accustomed to come alongside,

cranes are practically non-existent, beyond perhaps a few small derricks to swing out the hose connections. Bollards on such quays, however, require careful design, as they have to perform heavy duty without causing undue stresses on the quay.

In the case of riverside paper mills the leading feature of their quays is the necessity for suitable tracks alongside, separate from the crane tracks, and abundant deck space for the temporary storage of paper pulp. It would also be unthinkable on such a jetty to have any fixed rails or stanchions, for the craft attending the quays are generally relatively small and the berthing positions of the ships vary considerably. In the cement trade, again, barges have specially to be catered for and, as with a quay handling general merchandise, the question of electric, hydraulic, or even steam capstans assumes importance.

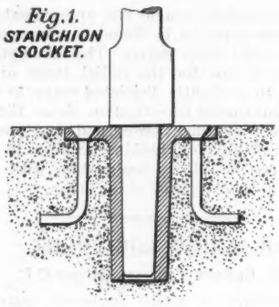
It will, therefore, be seen that it is not possible to lay down any definite specification for quay equipment or to attempt in any way to standardise it. A fairly long experience of this class of work, however, does indicate that there are many leading principles which should not, if possible, be departed from, and the following notes may, therefore, be of use in this respect.

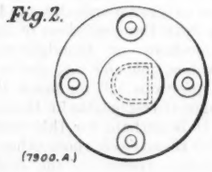
Stanchions for Chain Fencing.—These are, of course, usually of the removable type. One source of annoyance is the constant loss of the chains, and for this reason the end hook at one end of each chain should be shut into the eye on the stanchion so that it can only be unhooked at the other end. This seems an absurdly small point, but, nevertheless, it is frequently overlooked. It follows that each stanchion should register the same position when replaced in its socket to prevent two chain attachments from opposing each other, or the eyes in the stanchion from being at right angles to the line of chains. It will be seen that with a spigot of circular or square section at the base of the stanchion this can easily happen. To avoid this it is desirable to forge the spigot to a "D" shaped section, as shown in Figs. 1 and 2. This example is taken from a chain fence recently erected, and is an improvement on some other designs. The spigot should never be less than 5 in. long. In the case in question the sockets are let into a reinforced concrete deck and would clearly have to be modified in design if intended for attachment to a timber kerb. It is a noticeable feature in timber quays that the stanchion sockets are usually too light and the timber decays round them when they soon become displaced. This can be remedied by employing a socket with a liberal flange, and providing never less than four bolts through the kerb with a steel plate washer below.

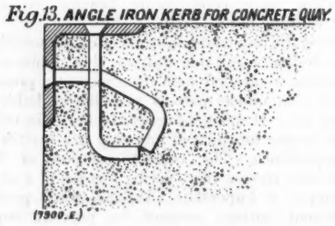
Fixed Railings.—These become a necessity on pier approaches and along the backs of jetty heads. A great variety of design exists but, apart from promenade piers, it must be remembered such railings on commercial jetties are liable to very rough usage. Despite any regulations to the contrary, barges will frequently tie up to them, and cranemen being only human, sometimes misjudge their distance, and the crane load often hits the top rail. The question of strength, therefore, is important. Figs. 3 and 4 illustrate a useful type of fixed rail standard. This rail is constructed with cast-iron standards at intervals of about 10 ft., and the two rails themselves consist merely of 2 in. diameter gas barrel passing through each standard. This type of railing has one feature worth noting. It frequently occurs that, although a fixed railing is called for, occasionally access at certain points overside is required. With this type of railing, a sliding panel can readily be introduced by utilising a smaller diameter gas barrel passing inside the standard tubes of the normal bays. The outer ends of these smaller tubes are permanently fixed to a movable standard which can travel on runners in a small channel laid in the deck. In the shut position the movable standard is locked or pinned in position, but when released, the movable bay can be pushed backwards into the adjacent fixed section. This was employed with advantage a few years back in a jetty where occasionally a ship's rope required a lead in a special direction. It can also be used for passenger landing stages where the berthing position between ship and stage is more or less fixed. Figs. 5 and 6 illustrate a telescopic bay of this character. The movable stanchion and runway can, of course, be omitted, but it is not recommended as the loose tubes are easily bent at the free ends.

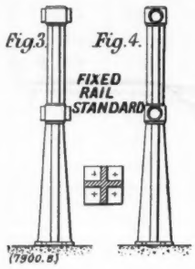
Bollards.—The design of bollards cannot, of course, be standardised. In the case of a timber structure, the attachment of the bollard to the quay itself requires attention. It is a mistake to attach a heavy cast-iron bollard to 3-in. or 4-in. thick desk planking, as a moderate stress will detach the bollard. For this reason it is always desirable to put in special members to carry the bollards and to attach the former rigidly to the main piles of the quay. In a solid masonry or brick faced quay, the bollards should have special mass concrete foundations behind the quay face. Where the quay is constructed in reinforced concrete (a common practice to-day) it is wiser to cast the bollards to a relatively thin and light section and to fill them up from the top with mass concrete. In this way the actual steel reinforcing bars of the main structure can be brought up into the interior of the bollard castings which, in this way, are properly married into the quay. Here, again, it is clearly inadvisable to depend simply on an attachment to deck reinforcement and the bollards, if possible, should therefore come immediately above principal and vertical members of the quay, such as piles, cylinders, or counterforts, and their interior reinforcement should be the vertical continuation of the reinforcing bars of the latter. Figs. 7 and 8 show such a type of single bollard.

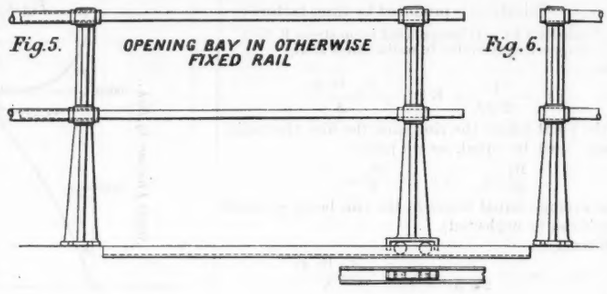
Bollard Piles.—These are by no means a necessity on all quaysides, but where small craft and barges are about they cannot well be avoided. They are a nuisance on a quay as a rule, and are liable to subject a piled structure to undue stresses if improperly used, as they frequently are. Bollard piles should always be of the driven variety, *i.e.*, it is bad practice to extend a so-called fender pile above deck level to act as a bollard pile. The heads of such piles, if in timber, are unprotected, and must be shielded from weathering by a cap. A suitable design of cast-iron cap is indicated in Figs. 9 and 10. This design, however, does not protect the pile above deck level from chafing by ropes and hawsers. This may be overcome by shaping the pile below the cap to a concave profile and screwing on a number of small "half-round" steel strips, say at 2-in. intervals. The objection to this, however, is that the light steel sections soon become dislodged and fray the ropes. A better design is that now

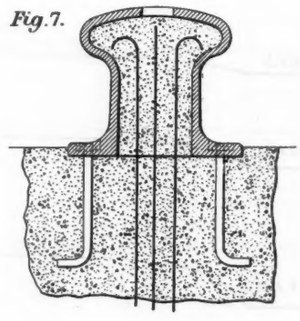


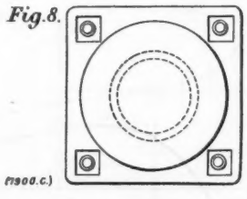


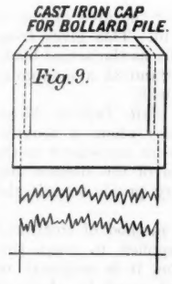


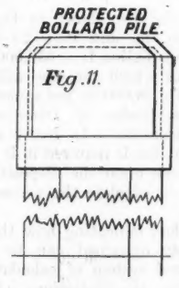


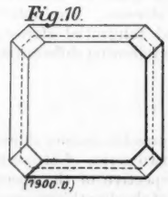












being adopted at Fresh Wharf, London Bridge, where the bollard piles are protected above deck level as shown by Figs. 11 and 12. In this type of protection, four fairly heavy steel sections can be employed at each corner of the pile and can be firmly bolted diagonally right through the latter. Bollard piles are not really practicable in reinforced concrete, as the heads of driven piles have generally to be cut away in order to bond the reinforcement into the deck beams. If a special or extra reinforced concrete pile is driven it has to be sheathed in cast-iron or steel in a similar way to a timber pile, but the expense in this case is usually prohibitive compared with simple castings suitably attached to the principal reinforcement of the structure.

Moorings.—These present little difficulty on a quay within a dock floatage where the variation in water level from time to time is not great. In tidal waters, however, along a continuous quay frontage the question is more important. It was thought that the rise and fall of the tide might interfere with the efficient mooring of steamers at the Tilbury Deep Water Cargo Jetty, which is in reality a continuous quay frontage 160 ft. out in the river. The difficulty was got over by introducing vertical sliding moorings on the quay face. The sliding rings are fastened on 6-in. steel stanchions and these, in turn, are bracketed on to the concrete cylinders of the jetty (see Sir Cyril Kirkpatrick, page 151, vol. cexiii Proceedings, Institution of Civil Engineers, and the illustrations on the following page). These moorings were added to the jetty early in 1921, and are reported to have given every satisfaction. In other cases where the quay face is not continuous and not too far from the shore, this difficulty can be got over in tidal waters by carrying the breast ropes of the ship ashore clear of the jetty (*i.e.*, ahead and astern) and providing heavy bollards on the river bank. This is the method adopted at most of the oil wharves on the River Thames.

Kerbing.—The kerbing along the edge of a quay merits consideration. In the case of a timber dock, it is usual to find a 9-in. by 6-in. kerb in pitch pine. This is not really good practice as, in time, the rough handling of the standards (usually socketed in the kerb) and the chafing of overside ropes destroys the kerb, while there is the further disadvantage of the kerb usually having to project above deck level, a source of real danger if deck hands happen to trip over it. This projection above deck level often occurs in concrete work and is apparently the perpetuation of an error resulting from the copying of older designs in timber. As a general principle, the kerb should be kept level with the deck. This may be done in timber by stopping off the deck a few inches from the outer capping-piece and bolting thereon a steel rail of a section having the same depth as the thickness of the decking. The small space between the rail and the scar ends of the decking can be made good with asphalt.

In the case of concrete designs the writer now adopts the type of kerb shown in Fig. 13. This consists of nothing more than an angle-iron provided with hook bolts at intervals for bonding into the concrete work. It has the advantage of being cheap and efficient, and does not interfere with free drainage from the surface of the deck. Weep holes have to be provided in the case of a raised kerb, and these frequently get choked, resulting, after rain, in standing water lying between the kerb and the top of the deck camber.

In the case of quays of the solid-fill type, the kerb is usually in granite or other hard material and calls for no special remark.

Ladders.—For the safety and convenience of watermen access ladders from the deck to the water's edge have always to be provided. This would seem at first sight to be a simple matter not admitting of argument. As a matter of fact, this is far from being the case. Wharfingers, berthing masters and the watermen themselves all have very decided opinions on the question and seldom agree. The correct positions for the ladder is the first problem to solve.

The following considerations enter into this.

Firstly, one or more ladders must be provided on the jetty face for the purpose of bringing in ship's ropes.

Secondly, when a ship is alongside, the above ladders are useless, and others must be provided clear of the berth, *i.e.*, in a recess on continuous structures or on the approaches, land sides, or ends of jetty heads. Interior ladders can sometimes be provided.

Thirdly, each ladder must be located so that it is as far as possible immune from damage from boats, barges, or other craft.

The first two requirements call for no further observation, but the third is difficult to meet. In a skeleton structure, interior ladders are preferable as regards immunity from damage, but they call for apertures in the deck, always an unsatisfactory feature in any design. Fig. 14 shows a good position for a ladder, as it is placed immediately under the lee of projecting vertical fendering, and is therefore unlikely to be damaged by floating craft. Such a ladder, however, will probably have to pass close to those horizontal members which are behind the fenders. The rungs of the ladder then tend to come too close to the quay face at places, and would not, in the ordinary way, permit of a sure foothold. The experiment is now being tried at one quay of advancing the rungs to the face of the ladder stringers where the latter pass close to the horizontal members of the quay face. The ladder as a whole, in this case, could otherwise not be advanced riverwards without the risk of damage but, by changing the rungs as indicated, 2 in. of additional clearance were gained (see Figs. 15, 16 and 17). The design of stanchions at the head of a ladder is important. The design recently adopted at Greenhithe for the Empire Paper Mills, a year or two ago, is illustrated in Figs. 18 and 19; this appears to afford a simple and efficient arrangement. On another site, however, this design was objected to on the grounds that in descending or coming off the ladder, a person would have to swing round the outside of one or other ladder stanchion and that the fencing chains would be in his way. This was, of course, a valid objection, and the design in the second case was altered to that shown in Fig. 20. This arrangement is satisfactory, but it could probably be improved upon by extending the angle irons forming the ladder stringers above the deck to replace the relatively light stanchions shown, which are liable to damage. The correct spacing of ladder rungs is 10-in. centres and, above all, there must be no variation in the spacing throughout the length of the ladder. If there is a variation, accidents may occur, as few users of ladders are as cautious as they should be in looking for their foothold.

Fendering.—It is not within the scope of the present article to discuss the general question of design. That subject is one of much controversy, and much remains to be done in the way of courageous experiment carried out with the object of avoiding the very considerable loss entailed from year to year through damaged fenders which the writer has so often drawn attention to. There are one or two details, however, well worthy of remark.

Timber fendering is usually (or should be) carried out in American elm. These members, however, split off at the bolt holes when they are forced in a direction parallel with the quay face due sometimes to ships' plating catching the edge of the fender. This occurs frequently, especially with modern vessels where vertical "proud" plate joints occur on the side of the ship. The suggestion is sometimes made that the fendering should be sheathed in steel. To some extent this would undo the very function which the fendering is called upon to perform and, if the sheathing becomes dislodged, as it certainly would sooner or later, it tends to become an actual source of damage to shipping. Shipowners object to berths so fendered, and this finally disposes of the proposal. One experiment of a simple nature is now being tried as follows. The fendering is in elm, and of the usual vertical type, but, on the outside of the fenders, thin elm rubbing pieces only 3 in. thick, and in short lengths, are being merely spiked on to the main fenders with 7-in. deck spikes, as shown in Fig. 21. It is hoped that these "veneers" will be carried away first in preference to the main fenders and, of course, the relatively cheap facing pieces can be easily and rapidly renewed at any time.

Power Capstans.—These notes would be incomplete without a brief reference to the use of electric or hydraulic capstans. The application of these efficient and simple machines has been too long neglected. They are capable of performing two functions, viz.: (1) Of being utilised in handling

Fig. 14. SUITABLE POSITION FOR ACCESS LADDER.

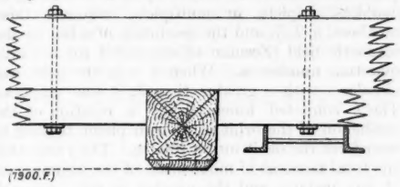


Fig. 15. NORMAL RUNG (PLAN)

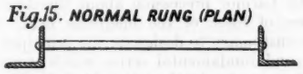


Fig. 16. ADVANCED RUNG (PLAN)

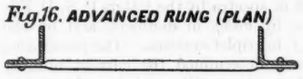
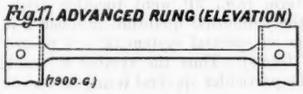


Fig. 17. ADVANCED RUNG (ELEVATION)



ACCESS LADDER AT GREENHITHE.

Fig. 18.

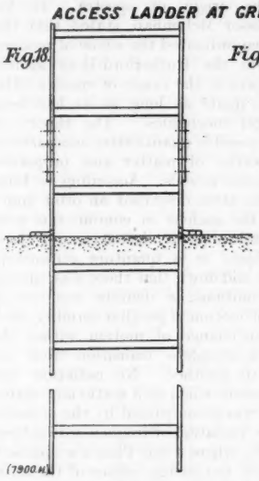


Fig. 19.

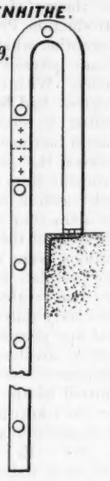


Fig. 20. ELEVATION OF ACCESS LADDER.

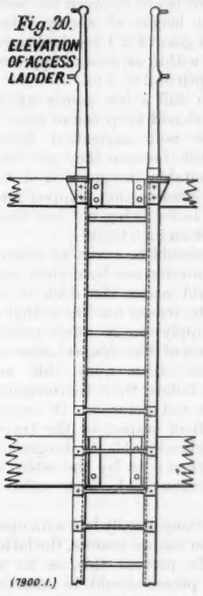
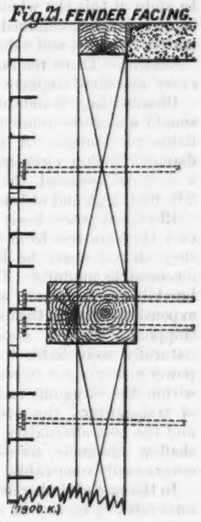


Fig. 21. FENDER FACING.



railway trucks on the quayside and (2) for warping and hauling barges and other small craft. At Tréport harbour in Normandy, mixed cargoes of small vessels of about 1,000 tons deadweight are handled daily inwards and outwards. The distribution to and from the hangars and the making-up of freight trains is dealt with by a system of small turntables, radial tracks, and electric capstans. These capstans are of neat design, with their motors completely below quay level, and they are handled with great skill. For this type of trade they represent an advance on ordinary electric traction, conveyors, or cable haulage. The maximum pull necessary for this class of capstan is under 200 lb. When, however, we come to deal with power-capstans for moving barges or hauling on ships' ropes, a minimum pull of about 1 ton is called for. Wharfingers are always afraid of eating into deck space by adopting "patent devices," but, as nowadays the capstan gear can generally be housed below deck level, there is very little in this objection. In the case of a special design now under construction, the available space was very limited in area and also as to depth below deck level, owing to the distribution of certain steel girders and timber bracing and the limited freeboard between the deck level and the maximum height of spring tides. In spite of this the whole gear of a 1-ton hydraulic capstan is being confined within an area of approximately 20 sq. ft. and a depth of 2 ft. 3 in.

General.—There remain still a few points which every maritime engineer should keep before him.

Illuminating standards and navigation lights should always be removable because they are very liable to damage. A suitable design is a 4 in. diameter hollow circular steel section shipped into a cast-iron pedestal, the latter being not less than 2 ft. 6 in. high and at least an inch thick.

Electrical power leads should be overhead wherever they are free from interference by cranes, and they should never be laid under the deck or in inaccessible conduits. The reason for this is that a breakdown in power supply on a quay causes expensive delays in the form of demurrage charges on shipping. Electric mains on a quay side are naturally more liable to failure than the ordinary power mains of our streets and factories. Of course, within the swinging radii of cranes, or the travel of transporters, the overhead cable is dangerous, and the best alternative then is to lay the cables in shallow channels across the deck with suitable covers easily removable.

In the case of timber decking usually laid with open intervals of ¼ in. to 1 in. on timber bearers, the latter will very soon decay. To prevent this, as far as possible, small blocking pieces should be inserted between the deck planks to slightly overhang the bearers wherever the deck planks cross them.

There are, no doubt, many other points of importance, but experience shows the necessity of at least keeping the above desiderata in mind when specifying quayside equipment. Nothing is more disappointing to an engineer than to be responsible for heavy expenditure on perfectly sound construction only to find that, having ignored details of apparently minor importance, the finished quay is "unworkable" from the wharfingers' point of view, either from lack of—or from the wrong distribution or design—of the necessary accessories.

THE BRITISH ASSOCIATION.

(*Continued from page* 391.)

SECTION A.—MATHEMATICS AND PHYSICS.

The transactions of Section A, Sir Ernest Rutherford remarked during one of the discussions, would thirty years hence be quite as memorable as those of the Liverpool meeting of 1896 were now. A large number of the eminent workers on the new ideas were present; great progress had been made during the last few years, and we might cheerfully look to the future. Many of the best-known original workers in these fields took part in the discussions, and their names will be mentioned in our report; Professor Millikan was prevented from attending; none of the physicists from Austria, Germany and Scandinavia, often quoted during the discussions, were present. The physical lecture theatre of Professor L. R. Wilberforce, in which the Section met, was always crowded. The officers of the Section were: President, Professor J. C. McLennan, F.R.S., of Toronto; recorder and secretaries, Professors A. O. Rankine (South Kensington), H. R. Hassé and A. M. Tyndall (Bristol), Messrs. M. A. Giblett (Meteorological Office), J. Jackson (Greenwich Observatory), and J. Rice (Liverpool). The programme which we published some weeks ago underwent several alterations. The joint discussion on "Cohesion and Molecular Forces," which Sir W. H. Bragg had opened on behalf of Section A, was abstracted on page 359 of our issue of September 21. We do not adhere to the sequence of the agenda, but begin with the presidential address which was delivered on the Monday, September 17, since it formed the nucleus of the discussions and of most of the 27 papers brought before the Section.

The Origin of Spectra.

In his presidential address on "The Origin of Spectra," Professor J. C. McLennan gave an outline of the leading features of the quantum theory in its bearing upon the problems of atomic structure with special regard to radiations and recent progress in the theory of the origin of spectra. In his introduction Professor McLennan stated that the conception which co-ordinated the whole of modern atomic physics was the Rutherford-Bohr atomic model. With respect to the origin of spectra little progress had been made as long as we had been limited to classical mechanics. The theory of quanta had made possible quantitative comparisons between the properties of matter and properties deducible from atomic models. According to Bohr each electron in an atom described an orbit under the attraction of the nucleus in combination with the fields of the extra-nuclear electrons, and those motions were subject to a quantum censorship. The postulate was laid down that there was, among the conceivable motions, a definite number of stationary states of motion of peculiar stability, such that any permanent change of motion within the system involved a complete transition from one stationary state to another. No radiation was emitted by the system when in a stationary state; but the transition was accompanied by the emission of monochromatic radiation of frequency ν, subject to: $h\nu = E_1 - E_2$, where h was Planck's constant, and the E indicated the energy values of the atom in the initial and final states of the transition. Conversely absorption by the atomic system of radiation of that frequency would result in the transition back to the initial state.*

The combination principle of Ritz asserted that the frequency ν of any spectrum line could be expressed by $\nu = T_1 - T_2$, the difference of two spectral terms T characteristic for the respective element. When these T terms were multiplied by h, they marked the energy levels of the different orbits in the atom, and on the Bohr-Coster theory the law of of Ritz meant that the spectrum in question originated in the transitions between stationary states of these energy relations. Thus a connection between the series spectrum and the structure of the atom was established. As the number of electrons within the atom was given by the atomic number of the element, the problem was to assign, to the constituent electron, orbits of such size and form so as would provide the values for the energy levels determined by the spectral series terms. The energy levels were determined by Moseley and by Franck and Hertz (and McLennan) by causing the atom to emit limited portions of its spectrum under bombardment by electrons of selected speeds; thus unknown spectra could be predicted.

In the Balmer series of hydrogen the various frequencies ν were given by $\nu = K\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$, where n_1 and n_2 were integers, and K was the Rydberg constant common to most series. Now when an electron described an ellipse about its nucleus, the major axis $2a$ of the ellipse would vary inversely as w, the work required completely to remove the electron from the field, so that $2a = e^2/w$, where e was the electronic charge. If then we took $2a = e^2n/kh$, a set of stationary elliptical orbits was clearly defined. But for each value of n several values of the axis $2a$ were possible, and hence several ellipses of different eccentricities were also possible. For $n = 1$, only one orbit would indeed exist; but for $n = 2$, there would be two orbits, since $2 = 1 + 1$, or $2 + 0$; for $n = 3$, three orbits, since $3 = 1 + 2 = 2 + 1 = 3 + 0$.

The spectrum of hydrogen showed these various ellipses in the Lyman, Balmer and Paschen series. The values of n hence became characteristic for the orbits, and were known as the "quantum numbers." In the recent extensions of the theory by W. Wilson and Sommerfeld, the quantum was applied to momentum rather than to energy, and both the angular and the radial momenta of the electrons were quantised. The formula involved the masses M and m of the nucleus and the electron, and had enabled Fowler to evaluate the values of the Rydberg constant in the hydrogen and helium series spectra.

In the simplest treatment of the hydrogen spectrum one quantum number n was sufficient. The definition of the fine lines required an additional quantum number k; series spectra consisting of doublets, triplets or multiplets, required three numbers, n, k, j, and the resolution of a line by the magnetic field (Zeeman effect) called for a fourth quantum number m. When $n = k$, the orbit was circular; with n greater than k, it was elliptical. The k connoted kinematically a rotation of the perihelion of the orbit in its own plane, tending to transform the orbit into a rosette. The j indicated the total moment of momentum of the atomic state at any instant, and the number m was connected with the Larmor precession about the direction of the lines of force of the magnetic field. It was further customary to designate the principal, sharp, diffuse and fundamental series which were distinguished in spectra by the letters P, S, D, F in singlet systems, by $\pi\sigma\delta\phi$ in doublets, and by the letters p, s, d, f, in triplet systems. The principal quantum number n determined the current number of the series term (*e.g.*, 2P went together with $n = 2$), while the azimuthal quantum number k indicated the type of spectral system ($k = 4$ referred to F, ϕ or f terms). Thus the symbol n_k would define both the particular spectral term and the electronic orbit.

The original theory of Bohr was developed by the principal of selection of Rubinowicz and Sommerfeld, involving intensity and polarisation, and by other rules, and quite recently by the correspondence principle of Bohr, which Professor Bohr himself explained subsequently at the meeting. As regards the genesis of atoms, Bohr suggested that electrons were successively bound by an originally naked nucleus to take up certain orbits characteristic of the *normal* state which would approximately be defined by the n and k; the motion of each electron could thus be described as a plane periodic motion on which a uniform rotation in the orbit was superimposed. During the binding of the electrons the values of the n and k characterising the orbits of the already-bound electrons were to remain unchanged on the whole, though the addition of electrons might cause slight alterations in the orientation of the electrons. These views were largely based upon the study of the *arc* spectra, which were believed to be emitted during the process of the binding of the last electron in the formation of a neutral atom. X-ray studies had given confirmatory evidence of stages in the process of reorganisation through which an atom passed after a disturbance in its interior. Some of the results of the researches were summarised in the table given on page 423—the gaps of which, we should say, do not all indicate missing elements, but rather elements which had not yet been particularly studied for these purposes. The values of N indicate the atomic numbers. The orbits, it will be seen, are divided into groups corresponding to the value of the principal quantum number n, and into sub-groups corresponding to the k. Thus in the fourth column the n is always 3, while the k takes the successive values 1, 2, 3. The vertical rows of figures mark the number of electrons in the successive shells or rings, numbers in brackets being

* The general difficulties of the conception of a discontinuous emission and absorption of energy in distinct quanta were not discussed at the meeting; we might refer our readers to the discourse on "Radiation" by Professor H. A. Lorentz, which we dealt with in Engineering, of June 8, last, page 718.

uncertain. All the elements (except hydrogen) have two innermost electrons, and then groups of 4, 6 or 8 electrons, and finally 1 or 2 outermost electrons. In the inert gases, helium He, neon Ne, argon A, krypton Kr, xenon Xe, niton Nt, the loose outermost electrons are absent.

How complicated the electron orbits would be, even in the simple hydrogen case (the atom consisting of one nucleus and one electron), is shown in Fig. 3. The binding of the nineteenth electron by a potassium atom was exemplified by a similar diagram. In the diagrams exhibited, the 18 electrons (in groups of 2, 4, 4, 4, 4) already bound in normal orbits were shown by closed curves, the nineteenth electron being bound was indicated by an open loop. It will be noticed further in the Table that at certain spots inner groups of electrons appear, *e.g.*, at Sc 21 (scandium). This element was the first of the family of the iron elements to which, in addition to titanium Ti (to be seen in the Table), belong also vanadium, chromium, manganese, iron, nickel and cobalt (all omitted in the Table). The group of orbits in this case is of the 3_3 type. The extra inner electron makes the individual difference, whilst the family character was maintained in the main group of electrons. Similar features characterise the rare earths and the platinum families. Further reference to groups of electrons in formation was subsequently made by Dr. Coster.

Professor McLennan passed on to special features. The fine structure of the hydrogen lines was ascribed

Table of Electronic Orbits in Atoms of the Elements.

N°	1_1	$2_1\ 2_2$	$3_1\ 3_2\ 3_3$	$4_1\ 4_2\ 4_3\ 4_4$	$5_1\ 5_2\ 5_3\ 5_4\ 5_5$	$6_1\ 6_2\ 6_3$	$7_1\ 7_2$
1 H	1						
2 He	2						
3 Li	2	1					
4 Be	2	2					
5 B	2	2 (1)					
10 Ne	2	4 4					
11 Na	2	4 4	1				
12 Mg	2	4 4	2				
13 Al	2	4 4	2 1				
18 A	2	4 4	4 4				
19 K	2	4 4	4 4	1			
20 Ca	2	4 4	4 4	2			
21 Sc	2	4 4	4 4 1	(2)			
22 Ti	2	4 4	4 4 2	(2)			
29 Cu	2	4 4	6 6 6	1			
30 Zn	2	4 4	6 6 6	2			
31 Ga	2	4 4	6 6 6	2 1			
36 Kr	2	4 4	6 6 6	4 4			
37 Rb	2	4 4	6 6 6	4 4	1		
38 Sr	2	4 4	6 6 6	4 4	2		
39 Y	2	4 4	6 6 6	4 4 1	(2)		
40 Zr	2	4 4	6 6 6	4 4 2	(2)		
47 Ag	2	4 4	6 6 6	6 6 6	1		
48 Cd	2	4 4	6 6 6	6 6 6	2		
49 In	2	4 4	6 6 6	6 6 6	2 1		
54 X	2	4 4	6 6 6	6 6 6	4 4		
55 Cs	2	4 4	6 6 6	6 6 6	4 4	1	
56 Ba	2	4 4	6 6 6	6 6 6	4 4	2	
57 La	2	4 4	6 6 6	6 6 6	4 4 1	(2)	
58 Ce	2	4 4	6 6 6	6 6 6 1	4 4 1	(2)	
59 Pr	2	4 4	6 6 6	6 6 6 2	4 4 1	(2)	
71 Lu	2	4 4	6 6 6	8 8 8 8	4 4 1	(2)	
72 Hf	2	4 4	6 6 6	8 8 8 8	4 4 2	(2)	
79 Au	2	4 4	6 6 6	8 8 8 8	6 6 6	1	
80 Hg	2	4 4	6 6 6	8 8 8 8	6 6 6	2	
81 Tl	2	4 4	6 6 6	8 8 8 8	6 6 6	2 1	
86 Nt	2	4 4	6 6 6	8 8 8 8	6 6 6	4 4	
87 —	2	4 4	6 6 6	8 8 8 8	6 6 6	4 4	1
88 Ra	2	4 4	6 6 6	8 8 8 8	6 6 6	4 4	2
89 Ac	2	4 4	6 6 6	8 8 8 8	6 6 6	4 4 1	(2)
90 Th	2	4 4	6 6 6	8 8 8 8	6 6 6	4 4 2	(2)
118 ?	2	4 4	6 6 6	8 8 8 8	8 8 8 8	6 6 6	4 4

(8073.B.)

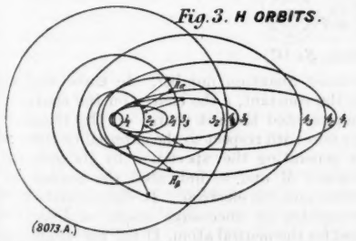


Fig. 3. H ORBITS.

by Sommerfeld to a relativity effect, the variation of the mass of the electron with the speed. Each Balmer line should be a doublet, a view which was confirmed by Paschen, and more fully by G. M. Shrum, of Toronto.

The two orbits of the helium electrons could not be in the same plane, as Bohr first believed, but must be intersecting ellipses; but the experimental ionisation potential of helium, viz., 24·5 volts, the highest known, appeared, according to Kramers, Bohr's assistant, to be theoretically too high. The study of the resonance and ionisation potentials showed that it was really the last-bound electron (of the type n_1, *e.g.*, where n might be anything up to 7 in the Table, but where k mostly had the value 1), which was driven out in ionising an element by successively raised potentials. The phenomena of multiple ionisation were subsequently discussed by Professor Fowler.

The number of electrons bound, Professor McLennan continued, would be sufficient to neutralise the nuclear charge, and if a loosely-bound electron were detached from the neutral atom, the orbits which remained should be characterised by the same quantum number as defined them in the neutral atom. In this way the Kossel-Sommerfeld displacement law further explained why the arc spectrum of a monovalent positive ion would be identical, as to type of series, with the arc spectrum (or the neutral atom spectrum) of the element just below it in the atomic number sequence. It also accounted for the observation of McLennan and others that the spark spectra of the alkali elements were similar in type to the arc spectra of the rare gases; under moderate excitation potassium gave a series spectrum like the red spectrum of argon, but under violent excitation the blue spectrum of argon. The very intricate mathematics of the quantisation in space had been attacked by Ehrenfest and had been confirmed by the experiments of Gerlach and Stern. The latter made a stream of vaporised silver flow past the wedge-shaped pole of an electromagnet on to a glass plate on which the silver atoms were deposited in two separate beams, indicating that all the particles had either been attracted or repelled by the magnet, that they all possessed a magnetic moment, and were axially oriented in space, in the direction of the lines of force or in the opposite direction. That the inert gases were not paramagnetic had been considered by Bohr to show that their normal atoms had no angular momentum; quantisation in space would, however, allow of assuming that the momentum axes were perpendicular to the magnetic field so that the rare gases would appear to be diamagnetic, indications of paramagnetism being suppressed. Ehrenfest's adiabatic hypothesis of the Zeeman effect suggested that if the magnetic field were established slowly, the energy of the electron in its orbit and the frequency of its revolution might be changed without any change in the quantum number, so that the Lorentz theory of the Zeeman effect would still remain applicable on the quantum theory.

THE CORRESPONDENCE PRINCIPLE.

Professor Niels Bohr, of Copenhagen, in presenting his paper, said that he wished to show how—notwithstanding the fundamental departure, from the classical theories of mechanics and electrodynamics, of the new ideas, particularly in the postulate $h.\nu = E_1 - E_2$ where ν had no simple relation to the motion of the particles of the atom—a connection could be traced between the radiation admitted by an atom and the motion of the particles as in the classical theory of radiation. Professor Bohr considered an atomic system of many degrees of freedom. His strictly mathematical deductions led to the conclusion that the fundamental difference between the quantum theory and the classical theory did not vanish with large quantum numbers, though a connection between the statistical results of the quantum theory and the classical radiation theory was reached. The classical theory assumed continuous and simultaneous emission of wave systems of different frequencies, each corresponding to one of the harmonic components in the motion; on the quantum theory each train of waves was emitted by an independent process of transition between stationary states, the relative occurrence of the different processes being governed by the laws of probability. According to the correspondence principle every transition process could be co-ordinated with a corresponding harmonic component in the motion. That co-ordination involved that the occurrence of the transition depended upon the amplitude of the corresponding harmonic component, and that the polarisation of the radiation emitted during the transition depended upon the shape and orientation of the corresponding harmonic oscillation in a way analogous to that in which, on the classical theory, the polarisation of the radiation would depend upon the orbit of the emitting particle. The experiments on the action of electric and magnetic fields on spectra seemed to justify our using the correspondence principle as a guide in dealing with complicated cases of atomic structure.

THE STRUCTURE OF ATOMS AND THEIR MAGNETIC PROPERTIES.

In order to introduce the paper of Professor P. Langevin, of Paris, on "The Structure of Atoms and their Magnetic Properties," we may perhaps say broadly that he considers that the rotation of the molecules, each of which has a magnetic moment, is completely free, and that within the experimental range the magnetisation is proportional to the external field and inversely proportional to the absolute temperature. At Liverpool he dealt with the theory and with the fact, that the same substance, silver, for instance, can in its various compounds exist in the paramagnetic and diamagnetic states, from the standpoint of the quantum theory, and not as formerly, on the basis of statistical dynamics.

It was necessary, Professor Langevin stated, to assume that each atom or molecule possessed, in its normal state, a definite magnetic moment, which was proportional to the total amount of the quantity of electron movement. That moment might become zero, when the symmetry of the structure was sufficient, and would always be modified in the diamagnetic sense by an external field (the magnetic axes being then turned into positions at right angles to the magnetic field). From the point of view of classical dynamics a system of electrified particles which participated in thermal agitation would not exhibit, when isolated, nor could it assume under the action of an external magnetic field, any resultant magnetic moment, and could consequently not possess any magnetic property. The laws of quanta, on the contrary, immediately enabled us to predict the existence of molecular magnetic moments which were integrals of the Bohr magneton, and they alone allowed us to develop a coherent electronic theory of magnetism analogous to the theory of the atomic structure and of the emission of spectra.

He supported these views by deductions and new data, admitting that the family of the rare gases gave rise to interesting difficulties—features upon which Professor McLennan had dwelt in his address with reference to the work of Pauli. Thus, for instance, Professor Langevin pointed out, the three elements chlorine, argon, potassium, had the consecutive atomic numbers, 17, 18, 19, and had all the same number 18 of electrons if we considered the ionised chlorine atom (with one negative charge) and the ionised potassium atom (with one positive charge); but the magnetic moment of argon was ten times as large as that of the other elements, instead of having the same value, a difficulty which had to be faced. On the other hand, Professor Langevin continued, the variations of the magnetic properties with the state of chemical combination vindicated the quantum theory in a remarkable way. As the magnetic atoms of iron, cobalt platinum, etc., entered into more and more complex combinations, the ferro- or para-magnetism of these elements disappeared progressively; that showed that chemical affinity tended to the formation of molecules which had no resultant magnetic moment, and helped us to realise electronic edifices which presented a higher and higher symmetry.

THE SPECTRA OF THE LIGHTER ELEMENTS.

The discussion on the "Spectra of the Lighter Elements" took place on Tuesday, September 18, and was opened by Professor McLennan, who first dwelt upon the fundamental differences between the ultraviolet and the X-ray spectra of the lighter elements. In the former spectra, he said, an outer electron was removed, but the inner structure remained intact; in the latter an inner electron was ejected; yet lines of both these spectra would be intermingled in the ultraviolet region. He then reviewed the various methods used for filling up the originally large gap between the shortest ultra-

PULVERISED COAL INSTALLATION FOR PLATE-HEATING FURNACE.

CONSTRUCTED BY THE POWDERED FUEL PLANT COMPANY, LIMITED, ENGINEERS, LONDON.

(*For Description, see opposite Page.*)

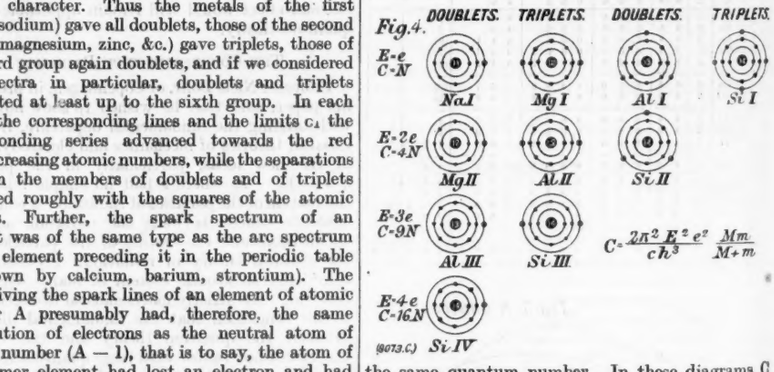
Fig. 1. View of Furnace with Pulverising Plant.

violet light waves and the longest X-ray waves. With the aid of quartz, fluorspar, and also celluloid, and the use of concave gratings, vacuum spectrographs and crystal and other X-ray absorption and photo-electric methods,* the gap had been narrowed down to the region 45 deg. A.U. to 12 deg. A.U. For exact absolute measurements the ruled grating—which, it was mentioned during the discussion, could now be more readily obtained from the National Physical Laboratory than from Baltimore—and crystal gratings possessed advantages over the other instruments.

The study of the radiations which the atoms of the lighter elements could be made to emit had been particularly instructive for the determination of the electronic orbits of neutral atoms, and Professor McLennan proceeded to give an account of recent work in this field by Hughes (on boron) F. Simeon (on the carbon arc, with the aid of a Hilger vacuum spectrograph) and others. His own work concerned the elements carbon, boron, beryllium, and lithium, and the determination of the critical K and L absorption wave-lengths. The substance under test was melted or fixed in a recess of the anti-cathode (which was earthed and water-cooled) and bombarded by electrons from a tungsten filament. He found that the Moseley linear law connecting the square root of the frequency of the critical absorption wave-length with the atomic number of the element held for the K series down to the lithium, but that it did not hold for the L series in the case of elements lighter than argon. His interpretation of these results, Professor McLennan added, did not agree with the views of Professor Millikan.

Professor A. Fowler, F.R.S., following Professor McLennan, said that our knowledge of the series spectra of the lighter elements, of special interest in relation to the connection between optical spectra and X-ray spectra, was still meagre, but progress had been made with respect to some spectra at different stages of ionisation. These problems, we may remark, have occupied Professor Fowler since 1914, but he has only quite recently published his results. It was common knowledge, he stated, that the spectra of elements of the same group were all of similar character. Thus the metals of the first group (sodium) gave all doublets, those of the second group (magnesium, zinc, &c.) gave triplets, those of the third group again doublets, and if we considered arc spectra in particular, doublets and triplets alternated at least up to the sixth group. In each group the corresponding lines and the limits c_∞ the corresponding series advanced towards the red with increasing atomic numbers, while the separations between the members of doublets and of triplets increased roughly with the squares of the atomic weights. Further, the spark spectrum of an element was of the same type as the arc spectrum of the element preceding it in the periodic table (as shown by calcium, barium, strontium). The atom giving the spark lines of an element of atomic number A presumably had, therefore, the same distribution of electrons as the neutral atom of atomic number (A — 1), that is to say, the atom of the former element had lost an electron and had become ionised. That this held quantitatively for helium and the alkaline earths was proved some years ago, and the calculations of the series constant, from the identification of a sufficient number of the series, gave in that case the value 4 N* (instead of, 1 N for hydrogen) ; that indicated single-ionisation loss of one electron. For multiple ionisation the series constant should then assume the values 9 N, 16 N, and so on, and that had been confirmed.

In these researches Professor Fowler had first worked on magnesium (atomic number 12), Paschen had then experimented with aluminium (13), and he himself again with silicon (14); he had selected silicon on account of its astrophysical interest, because the silicon lines represented successive stages of ionisation appearing in stars believed to be at successively higher temperatures. According to Bohr these atoms might diagrammatically be represented as in Fig. 4, electrons on the same ring having



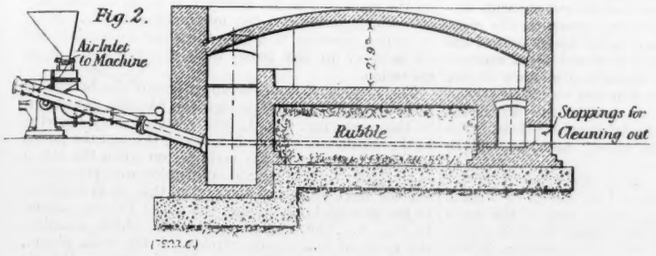
the same quantum number. In these diagrams C was the constant, e the charge on the electron, and E represented the net charge on the remainder of the atom with respect to the external electron which was generating the spectrum by its outward excursions ; M and m indicated the masses of the nucleus and the electron. To discriminate between the spectra at successive stages of ionisation, I stood for the neutral atom, II for the singly-ionised atom, III for the doubly-ionised atom, and so on. It would be noted that doublets and triplets alternated. When magnesium was single-ionised, its spectrum became similar to that of neutral sodium, Na I, with the difference that the constant was 4 N ; Al I should give doublets of constant N, Al II triplets of constant 4 N, and Al III again doublets, but of constant 9 N.

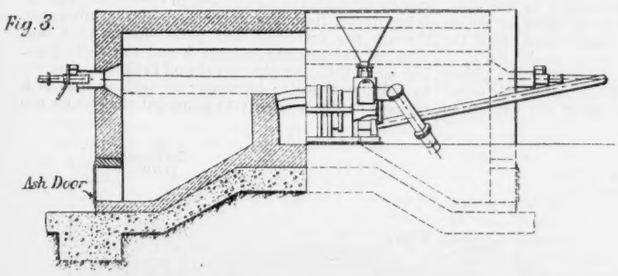
* We would refer our readers to Professor O. W. Richardson's lectures on the Disappearing Gap in the Spectrum, Engineering, June 2, 1922, page 691.

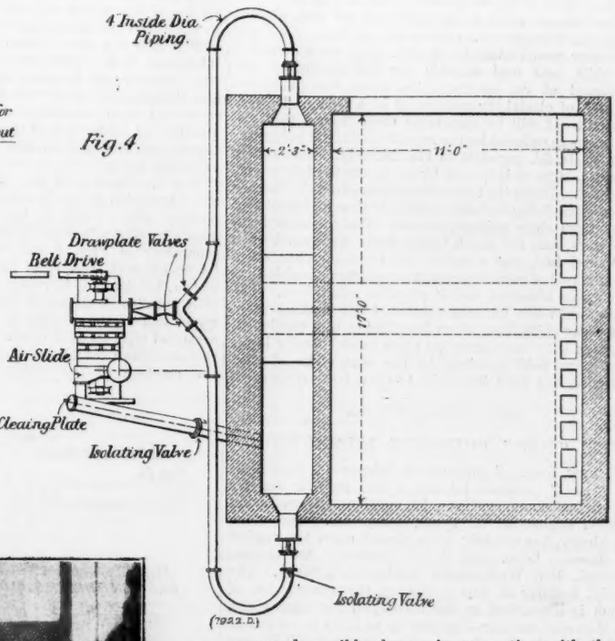
* Professor Fowler, uses the symbol N for the Rydberg constant, which Professor McLennan designated by K and Dr. Coster by R.

PULVERISED COAL INSTALLATION FOR PLATE-HEATING FURNACE.

CONSTRUCTED BY THE POWDERED FUEL PLANT COMPANY, LIMITED, ENGINEERS, LONDON.







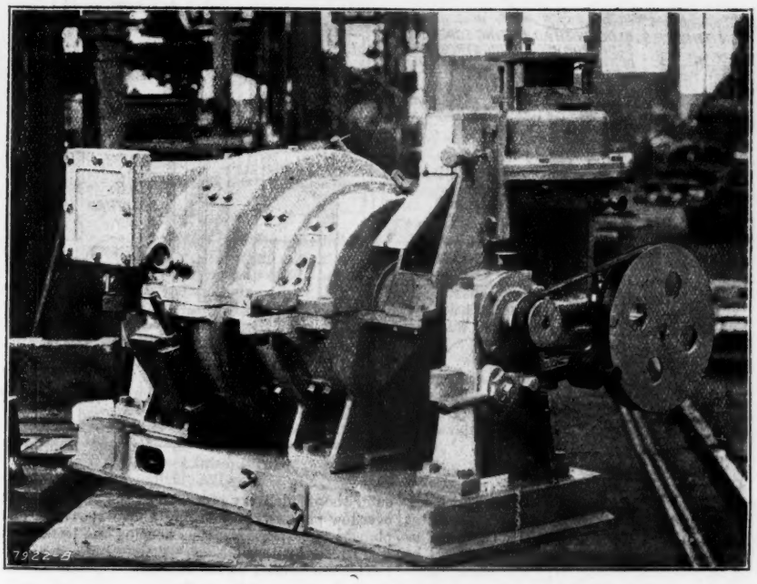


FIG. 5. COAL PULVERISER.

Similarly the silicon spectra Si I, Si II, Si III and Si IV should consist of triplets, doublets, triplets and doublets and of constants N, 4 N, 9 N, 16 N. All this was fully confirmed by experiments. As regards the lines corresponding to the D lines of sodium the wave-lengths were 5,890 and 5,896 with separation $\Delta\nu = 17{\cdot}2$ for Na I, and 1,394 and 1,402 with separation $\Delta\nu = 460$ for Si IV. the separations increasing as the wave-lengths decreased. The analogy extended also to the abnormality in the different triplets of Si III, which Paschen found again in Al II. These phenomena could be accounted for by successive losses of electrons, one by one from the outer ring. But electrons normally in the inner ring might also become effective; that might be expected from the fact that the alkali metals (which had only the electron in the outer ring) also gave spark spectra, and there might exist a spectrum Si V with the series constant 25 N.

With very powerful discharges the wave-lengths of the lines became very short, and the limits were apparently set only by the energy applicable and by the number of electrons available; but the high-frequency lines would be accompanied by less intense and less rectangular lines. The "vacuum-spark" discharge of Millikan did not appear to be more disruptive than the discharges used by Professor Fowler himself, and he expressed regret that the application of the nomenclature for X-rays (K, L lines, &c., of the elements lithium to fluorine) had been extended by Millikan to optical spectra. That caused confusion, expecially when several spectra were possible, one due to the neutral atom, the other to singly (or multiply) -ionised atoms. We were accustomed to associate X-rays with very short wave-lengths, and might restrict the term X-ray radiation to those produced by transitions to inner orbits of electrons from outer orbits which were normally occupied by electrons.

(To be continued.)

POWDERED FUEL FOR FURNACE WORK.

THE belief that powdered fuel installations necessarily involve large and costly drying kilns for the coal before pulverisation and an inordinate amount of labour, expense and possibly danger in connection with the handling and storage of the fuel, has undoubtedly done much to prevent engineers from looking so carefully into the question of adopting powdered fuel as the importance of the subject deserves. The extraordinarily low grade of coal which can be efficiently consumed in the pulverised form, and the ease with which furnace conditions can be regulated are, however, bringing the question more and more into prominence. The repugnance of engineers to the use of separate drying kilns and to the storage of large quantities of coal dust, has caused manufacturers to realise that these features of an installation, are not generally essential, and that individual pulverisers taking ordinary crushed coal and delivering it as impalpable powder to the burners of each furnace will provide all the advantages of the system without the obvious drawbacks referred to. The furnaces are thus all independent of each other, and the plant required for each is no more elaborate than a mechanical stoker.

Among the pioneers of pulverised coal in this country are the Powdered Fuel Plant Company, Limited, of 47, Victoria-street, London, who have carried out many installations in connection with power stations, industrial boiler plants and metallurgical furnaces. The plate-heating furnace, illustrated in Fig. 1, page 424, and Figs. 2 to 4, annexed, is one which the company some time ago converted from coal-firing to pulverised coal-firing at the works of Messrs. Thomas Piggott and Co., Limited, Spring Hill, Birmingham, and sufficient experience has now been gained to enable a definite comparison to be made between the results before and after the change. The furnace was originally of the ordinary reverberatory type with a hearth 17 ft. long by 11 ft. wide. A pulveriser was put down alongside the furnace, and driven by a motor mounted on a small platform built for the purpose. Crushed coal fed by hand into a hopper on the pulveriser is delivered in the form of dust to burners at each end of the furnace over the position of the old grates. The first position of these fuel pipes was as shown in Fig. 1, but they were afterwards changed to the positions shown in Figs. 3 and 4.

The coal used is slack which, as delivered from the colliery, passes a screen with eight meshes to the inch. The average analysis of a dried sample is as follows: Volatiles, 33·37 per cent.; fixed carbon, 50·45 per cent.; ash, 16·2 per cent.; and British thermal units, 10,000 per pound. The raw coal carries a total moisture content of 12 per cent. When the pulveriser was first installed, the practice was to dump the coal on an iron plate covering a flue near the furnace, and to throw it thence into the hopper of the machine as required. The heat of the plate drove off a good deal of the moisture, and the coal as pulverised was thus drier than the analysis above indicates. This practice has been now discontinued, the drying being effected in the machine itself by hot air taken direct from the

combustion space through the short straight pipe shown in Figs. 2 and 4. The amount of this air can be regulated at will, and the regulation of the cold air which is also drawn into the pulveriser is effected by the flap which is shown partially open in Fig. 5.

The furnace when hand-fired used 48 cwt. of coal per 8-hour shift, the coal costing 18*s.* per ton. After the pulveriser was installed, 32 cwt. only were required per shift, and coal suitable for the pulveriser was purchased at 8*s.* per ton. To drive the pulveriser 48 units of electricity were used at a cost of 1·125*d.* per unit. It will be seen from these figures that the fuel cost was reduced by the installation of the pulveriser from 2*l.* 3*s.* 2*d.* per shift to 17*s.* 3*d.* only. This saving however, large as it is, was by no means the full benefit obtained. When the furnace was hand-fired the furnace men did the firing and this took their time and attention away from their primary duties. Their release from this work, and the much better heats obtained by the powdered fuel, has enabled the furnace, when on a straight run of work, to produce an output double that which was obtained under previous conditions. The furnace-men are on piecework and are making more wages per shift than when hand-firing was employed, although they have accepted piece rates actually lower than were paid previous to the war. The change, therefore, has been beneficial to everybody concerned.

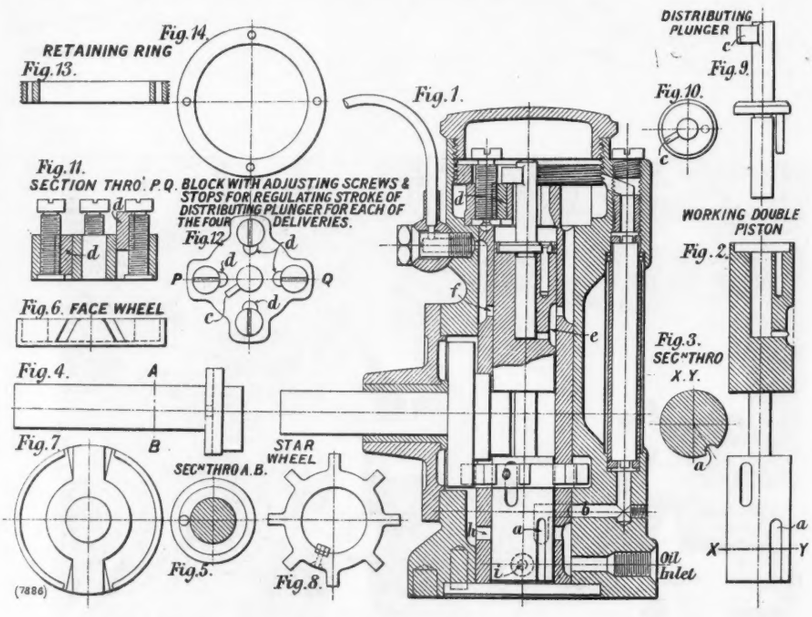
THE "REF" PRESSURE LUBRICATOR.

A new form of mechanical lubricator known as the "Ref" pressure lubricator and suitable for use on marine steam engines, locomotives, internal-combustion engines of all types, compressors and other machinery, has recently been placed upon the market by Messrs. Loco. and Auto. Economy Accessories, Limited, 183, Westminster Bridge-road, S.E.1. The special features of this appliance, the construction of which is illustrated in the accompanying engravings, are that any number of points up to 12 or more can be supplied with oil. For pressures up to 2,200 lb. per square inch lubricators with from 2 to 6 supply points can be used, while up to about 700 lb. per square inch the lubricators are adapted for the supply of a greater number of points. The quantity of oil delivered to each point can be independently adjusted from nothing to about 70 drops per minute. The lubricators can be employed with any system of lubrication and from the fact that the supply can be adjusted to meet the exact requirements of each point, their use is claimed to result in a very marked economy in oil. Another advantage claimed for the design is the entire absence of valves and springs, so that the action of the lubricator is unaffected by jolting or vibration.

Fig. 1 is a complete longitudinal section of a lubricator for supplying 4 points, and the main components are shown separately in Figs. 2 to 14. The body of the lubricator is an aluminium casting measuring 5¾ in. in height and 3 in. in diameter at the base. In this casting is fitted a gun-metal liner in which works a double piston of hardened steel. Reciprocating motion is imparted to the piston, which is illustrated separately in Figs. 2 and 3, by means of an eccentric cam formed on the end of a short horizontal shaft shown on the left of Fig. 1 and also in Figs. 4 and 5. The shaft normally runs at about 60 r.p.m. in either direction, and on it is mounted a special form of face wheel illustrated in Figs. 6 and 7. This wheel has two teeth at the opposite ends of a diameter, as shown in Fig. 7, and these teeth engage with a star wheel having 8 teeth and encircling the piston as shown in Fig. 1. The star-wheel itself is illustrated in Fig. 8, and this figure shows the small feather which fits into a slot formed in the cylindrical surface of the piston so that the latter can be rotated about its longitudinal axis by the rotation of the star wheel. The rotation of the piston takes place at the end of each up and down stroke when one of the teeth of the face wheel comes into contact with one of the teeth of the star wheel, moving it, and the piston, through one-eighth of a revolution. It should, perhaps, be pointed out that, except when the teeth of the face wheel and star wheel are in actual engagement, the latter is prevented from rotating by the fact that two of its teeth are in close proximity to a rim formed on the face wheel as indicated by the dotted lines in Fig. 6. Slots are cut in this rim, one on each side of the teeth, to enable the teeth of the star wheel to clear it when actual rotation of the latter is taking place in either direction. The mechanism, in fact, is somewhat analogous to the one-tooth gear used in connection with the well-known Geneva stop for preventing the overwinding of watches.

The oil inlet shown in the base of the lubricator in Fig. 1 is connected to the supply tank, which may be any distance above, or as much as 20 ft. below, the level of the lubricator. On the suction stroke, a slot *a*, formed in the cylindrical surface of the piston, comes into coincidence with a port cut in the liner communicating with the oil inlet, and oil is drawn into the space below the piston. The rotation of the latter at the end of the suction stroke brings the slot *a* into coincidence with another port in the liner communicating with the passage *b* (Fig. 1), and on the next down stroke of the piston, the oil is delivered through this passage and the glass sight tube, shown on the right of Fig. 1, into a space formed in the upper part of the lubricator body; this space is closed by a screwed cap. One stroke in every eight is a suction stroke, and the quantity of oil raised in this way is greatly in excess of that necessary to supply the maximum quantity of oil to each of the lubrication points. The surplus is returned to the supply tank, as will be explained later.

The distribution of the oil to the connections for the lubrication points is effected by means of a small plunger which works in the upper part of the main piston as shown in Fig. 1; the plunger itself is shown separately in Figs. 9 and 10. The plunger, it will be understood, can slide longitudinally in the main piston, but is made to rotate with the latter by means of a pin clearly shown in the illustrations. Near the upper end of the plunger is a lateral projection *c*, so arranged that on each down stroke of the main piston the projection catches on one of four adjustable stops, the rotation of the piston bringing the projection over each of the stops in turn. The stops, which are lettered *d* in the illustrations, are fitted into a block best shown in Figs. 11 and 12, and they can be raised or lowered by means of cheese-headed screws as will be understood on reference to Fig. 11. The block carrying the stops is held in position in the lubricator body by means of the screwed retaining ring illustrated in Figs. 13 and 14.



As actually shown in the engraving, Fig. 1, the main piston is at the bottom of its stroke, but it will now be convenient to regard it as being at the top of the stroke. On the down stroke from this position, the distributing plunger will first descend with the main piston until the projection on the plunger comes into contact with one of the stops. The movement of the plunger will then cease, and the continued downward movement of the piston will leave a space below the plunger, into which oil will be drawn from the upper part of the lubricator body through the ports and passages shown towards the right of Fig. 1. At the end of the down stroke, the piston will be rotated through an eighth of a turn, bringing the passage *e* into communication with one of the ports, such as *f*, leading to the delivery points, and on the upward stroke, the oil in the space below the plunger will be forced out through one of the delivery ports by the flange on the plunger coming into contact with the bottom of the block carrying the adjustable stops. There are, of course, four inlet and four delivery ports in the liner, one of each for each of the lubrication points, and the slot *e* in the main piston is put into communication with each inlet and delivery port in turn as the piston rotates. It should now also be clear that the maximum volume of the space below the distribution plunger, and consequently the quantity of oil drawn in and delivered at each stroke, is dependent upon the height at which each of the adjustable stops is set. As drawn in Fig. 1, the stop *d* is in its lowest position, and no oil would be drawn in or delivered from the connection controlled by that stop. The stop shown on the right of Fig. 11, however, is in its highest position which would give the maximum delivery. It is, of course, possible to adjust the stops to regulate the oil delivery to any point while the lubricator is in operation.

The surplus oil from the upper part of the lubricator flows through an overflow pipe and passage, not shown in the engraving, Fig. 1, into what we may describe as the crankcase, whence it is drawn through the port *h* into the space below the main piston when the slot *a* in the latter comes into communication with the port *h*. On the next stroke of the piston, this oil is returned to the storage tank through the outlet *i* shown dotted in Fig. 1. The remaining strokes, which complete the cycle of four double strokes of the main piston, merely circulate the air enclosed in the system, the air being drawn from the upper part of the lubricator, through the crankcase and ports similar to *h* and returned through the passage *b* and the sight glass. The air bubbling up through the oil in the latter serves to indicate that the lubricator is working, but it is perhaps hardly necessary to point out that no air can enter the oil delivery pipes, since the entrance to the overflow pipe is considerably above the level of the plunger inlet passages, thus keeping the latter always well covered with oil.

The connections to the lubrication points are made by ball sockets held up to the casing by studs as shown in Fig. 1; the pipes can thus be led off at any angle. The delivery pipes can, of course, be fitted with sight feeds, try cocks, or back-pressure valves if necessary. Lubricators similar in principle to that described are supplied in several types having deliveries up to 18 points supplied by a single piston to meet practically all requirements, some models being fitted with reduction gearing for driving from high-speed machinery and others with ratchet mechanism for driving from reciprocating parts; one type is arranged for the supply of grease and others are combined with the oil tank to form complete self-contained units. The "Ref" lubricator, we may add in conclusion, is of German origin, but we understand that arrangements have now been completed for its manufacture in this country.

Lectures on Recent Excavations.—A series of 20 lectures on "Recent Excavations" are to be delivered by Miss Claire Gaudet in the Lecture Room of the British Museum on Thursdays at 4.30 p.m., beginning yesterday. The aim of the lecturer will be to trace from the beginning the stages of architectural expression and construction as evolved from East to West, taking discoveries made in recent excavations as the basis. An account will be given of the building of some of the oldest structures in the world, bridges, towers and pyramids, and wherever possible the arts and crafts of the people will be described. Particulars are obtainable from the Hon. Secretary, 120, Cheyne-walk, Chelsea.

INDUSTRIAL NOTES.

THE negotiations which have been started with a view to an ultimate solution of the Boilermakers' dispute are being continued. Following upon the meetings at Carlisle, conferences have been held in London between representatives of the Boilermakers' Union and the Federation of Engineering and Shipbuilding Trades. An effort is now being made to arrange for an interview of a sub-committee of the General Council of the Trades Federation with the Shipbuilding Employers' Federation. If a conference can be arranged it is anticipated it will be held some time next week. From the various statements made it appears that the Boilermakers do not yet see eye-to-eye with the Trades Federation, or, as a matter of fact, with many of their trades union colleagues. One fact is significant, and that is that the Boilermakers' Society are convening a delegate conference for an early date.

Mr. Patrick Hastings, K.C., the Labour M.P. for Wallsend, addressing his constituents on Saturday, September 29, is reported to have stated that he did not believe that there would be work in the shipyards this winter or even next year, and that it was criminal on the part of the Government to buoy up the hopes of the people that they were going to get back to work. This undesirable outburst comes from an observer whose acquaintance with the situation must be very limited, but it may be the cause of much unrest. It found emphatic denial from Sir George B. Hunter and others, when they were interviewed by the Press. When asked for his views, Sir George stated that practically all the British yards, excepting two or three new ones which have never employed any men, have both shipbuilding and marine engineering work in hand. The moment that the present dispute with the Boilermakers' Society is ended a large number of men could be given employment. Repair work which was going abroad could also be obtained. Mr. Hastings has shown an absolute failure to recognise either the conditions of present-day industrial activity or the simple economic facts of production. To anyone with the merest acquaintance with the subject it must be more than obvious that the Boilermakers' dispute has had the effect of almost entirely closing the yards. Work is available whenever that devastating trouble is ended.

Yesterday the miners' leaders presented the following demands to the coalowners:—A readjustment of the basis of wages and profits, an increase of the minimum wage equivalent to the cost of living since 1914, and more detailed information of the costs "other than wages." The whole question of wage rates in the coal industry is, like that of any other trade, a simple case of production costs. The output per man has diminished (although a small increase has taken place this year). The reduced output per worker is the cause not only of low wages but of the high cost of living. Unless more coal is produced at economic rates there is little hope for any great change in employment returns. Cheap fuel means a great step towards cheap production of almost every commodity. When it is obtained the miner will profit with every other section of the industrial community. The vital question in the coal trade is the reduction of output. Remove that, and higher wages and better conditions will follow as a certainty. There is a very low percentage of unemployment among miners; but the lack of exertion among the men is one of the causes of the great amount of unemployment outside their ranks. The miners are to-day the most pampered among the trades unionists. They have the privilege of inspecting their masters' books, have a guaranteed minimum wage whether profits are earned or not, and get five-sixths of the surplus profits over and above their standard wage rates. These are the people who seek improvements, and they do so at a time when the uneconomic courses they pursue are creating the unemployment of others.

The Ministry of Labour announce that the number of persons recorded on the live registers of the employment exchanges in Great Britain as totally unemployed was, on September 24, 1,232,000. This was 4,847 more than in the preceding week, but 253,878 fewer than on January 1. In addition, the number working systematic short time and drawing benefit for intervals of unemployment was 74,800 on September 24, compared with 74,724 on September 17, and 56,261 on January 1.

Commenting on the recent increase in the numbers of registered unemployed, Mr. F. Bramley, secretary of the Trades Union Congress, referred in an interview with a Press representative to the possibility of the numbers being much increased during the winter. When local authorities are not only bankrupt, but are faced also with the destruction of their credit, he said the Government will find it absolutely necessary to treat the unemployment problem as a national problem. "The national resources must be utilised to deal with a national problem, and Labour has already submitted to the Government by deputations and by documents various proposals for dealing with the problem on this basis. There is an enormous field which is capable of development. Electrical power can be developed, docks, harbours and inland waterways can be extended, and in many other directions there is much work of a constructive character that can be done." At present, he stated, we are spending enormous sums of money annually for which we get no return. It would be much better to utilise public money in subsidising work than in providing benefits for the unemployed for which we get no return.

At a large gathering of railwaymen at the Alhambra Theatre, Barnsley, on Sunday, September 30, Mr. J. Marchbanks, President of the National Union of Railwaymen, referred to what he termed the coming crisis in the railway world, and appealed for the unity of all grades of the men for the preservation of conditions. As the workers in many industries are being gradually driven back to worse conditions than existed in pre-war times, he stated that the railwaymen could not regard themselves as immune from this general attack. He later referred to the sacrifices of wages already made by the railway workers, and suggested that the only hope for the men in preventing further reductions was in the presenting of a solid front to any attack, by the union of all sections.

It seems difficult to anyone but an official of a union to understand why the railwaymen should not be subject to reductions as well as other classes of labour. The fundamental aim of all who have the interests of industrial well-being at heart is to get production back to an economic state, when goods can be made, handled on the railways and shipped abroad at such rates as will make competition with other countries a practical possibility. Then, and then only, can men be said to earn their livelihood. Further reductions in the cost of living will follow and the true wages will thus be increased. There is a great reluctance shown by all trades union leaders to deal with economic problems or to show the men that their labour, like that of everybody else, is remunerated according to the service rendered and the demand for it. It seems more reasonable to work for a smaller wage while trade is bad in order to improve conditions than to stand out for what cannot be obtained and thus cause a deadlock. Many of the trades union leaders have got into the habit of imagining that only the so-called workers are making sacrifices. At any rate, their speeches show that attitude. That is far from the truth, for all classes have suffered and do so with little grumbling in many cases. There is more reason for the general action of all to put up with adverse conditions for the necessary interval which must elapse before industrial work can be made truly prosperous. Unity, not of subsections, but of all the people of the country for the recovery of trade, is what should be our endeavour.

The coal trimming dispute shows no signs of improvement. It is now suggested that the whole strength of the National Union of Railwaymen, the General Transport Workers' Union and the Transport Workers' Federation is to be put at the disposal of the coal trimmers if the shipowners enforce the threatened reduction of 22½ per cent. in the national trimming tariff at all ports other than those in the Bristol Channel. The shipowners' reasonable proposal that the question be submitted to a Court of Inquiry has been turned down by the men, who insist that the rates at all ports should be brought into line with those paid in the Bristol Channel. This is entirely unacceptable to the employers, and thus there is a complete deadlock.

On Wednesday, September 26, at the termination of a lengthy meeting of the General Council of the Trades Union Congress, the secretary, Mr. F. Bramley, made a statement that they had asked the Prime Minister to postpone any action on the recommendations of the Anderson Committee on the conditions of service in the Civil Service, the Navy and the Army, as they thought the principles underlying the suggestions in the report were extremely reactionary and contrary to the democratic principles which they suggest should govern the relationship between State employees and the Government. As they are to press for an early personal interview with the Premier, we may obtain a more specific statement of what they take exception to. They also decided to co-operate with the Special Emergency Committee set up by the Parliamentary Labour Party with a view to submitting definite proposals on what they think the Government should do in connection with the distress arising through unemployment and the difficulties of local authorities in meeting their liabilities in the provision of relief. Representatives are to meet the unemployed workers' organisations regarding joint action on the same question.

A meeting of the National Federation of General Workers was held at the Memorial Hall, Farringdon Street, London, on Saturday last to discuss the threatened strike action in resistance of a proposed reduction of wages of municipal workers. A resolution was submitted and carried unanimously protesting against the refusal of the employers' side of the Joint Industrial Council for London to discuss the employees' case, and asking the Federation to take such action as will compel the Council to give full consideration to their demands regarding minimum wages and general conditions of employment. Mr. Jack Jones, M.P., said there was no need to strike, but to manifest their strength through the ballot boxes.

THE MICHELL CRANKLESS MOTOR-CAR ENGINE AND AIR COMPRESSOR.

IN our issue of March 11, 1921, on page 290, we illustrated and described a uniflow steam engine of the swash-plate type made to the designs of Mr. A. G. M. Michell, the inventor of the well-known thrust bearing which has so materially contributed to the development of marine propelling machinery. The Michell bearing principle was utilised in this engine for transmitting the force from the pistons to the swash plate, and by this means the lubrication difficulties which had proved formidable obstacles to the development of the earlier engines of this type were overcome. Another important feature of the Michell engine was the realisation of the inventor that, by suitably proportioning the masses and dimensions of the swash plate and pistons, it was possible to obtain a perfect dynamical balance of the moving parts, so that very high speeds of rotation were possible. The design, in fact, combines the advantages of the turbine from the point of view of balance, with those of the positive-piston type of engine, since it can be run at high, medium or low speeds with but little difference in efficiency, although high speeds are obviously essential where it is desirable to economise weight and space.

Since its introduction, the invention has been developed by Mr. Michell himself in co-operation with Crankless Engines (Aus.) Proprietary Limited, an Australian company, with registered offices at 9, Queen-street, Melbourne, not only in connection with uniflow steam engines, but also with internal-combustion engines of the motor-car, aircraft, Diesel and town-gas types, and various types of compressors, pumps, &c. For aircraft engines, the low weight, compactness and low head resistance of the Michell crankless engine has many obvious advantages which were promptly recognised both in this country and in the United States. The British Air Ministry, we understand, has been engaged in developing aircraft engines under the Michell patents for some time past, and we are informed that the second experimental engine constructed for them by Messrs. Rolls-Royce, Limited, has recently completed its trials with highly satisfactory results. In the United States, we understand, a 400-h.p., eighteen-cylinder crankless aero engine of the type referred to is now approaching completion. The mechanical principles involved certainly appear to have many possible applications of great utility, and the fact that they originated from the same source as the Michell bearing renders them of particular interest in this country where the value of the last-mentioned invention is now fully appreciated.

At the moment, however, we propose to confine our attention mainly to the engine as developed for motor-car purposes, since we have recently had an opportunity of inspecting at the works of Messrs. Sizaire Berwick, Limited, Park Royal, N.W. 10, an engine of this type brought over to this country for demonstration purposes by Major R. G. Casey, a director of the Australian company. This engine is of the eight-cylinder type designed to develop 35 b.h.p. at 1,250 r.p.m., but it will run quite satisfactorily, and with no noticeable vibration, at speeds up to 3,000 r.p.m., developing about 60 b.h.p. at that speed. In this connection we may remark that the valves and valve gear, which are of conventional design, impose a limit to the speed of the existing engine, but with specially designed valve gear and a suitable carburettor, the makers state that speeds up to 5,000 r.p.m. would be quite practicable.

Some idea of the external appearance of the engine can be gained from the photographs reproduced in Figs. 1 and 2, on page 428, while Fig. 3, on the same page, is a view of the swash plate (or "slant" as the inventor prefers to call it) and the main shaft with one pair of pistons in engagement with the slant; a pair of pistons is shown separately in Fig. 4. The complete engine contains four pairs of pistons with their axes parallel with the main shaft, the cylinders in which they

THE MICHELL CRANKLESS MOTOR-CAR ENGINE.

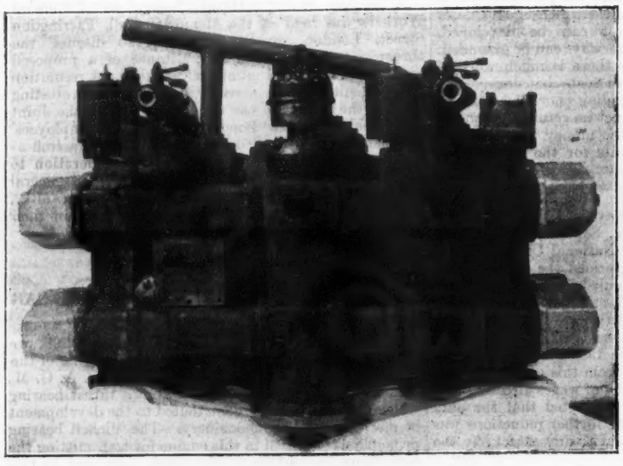


Fig. 1.

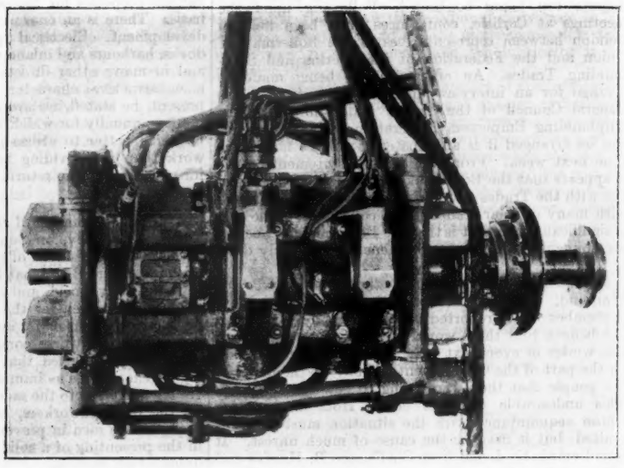


Fig. 2.

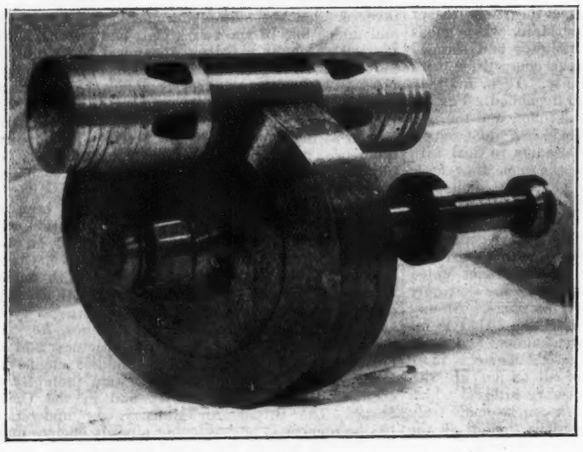


Fig. 3.

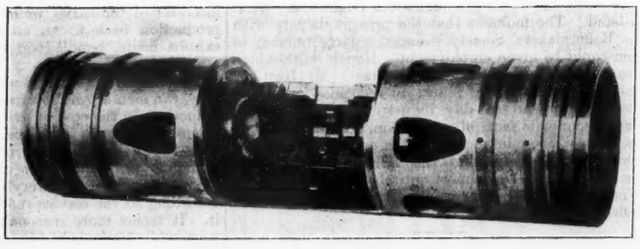


Fig. 4.

work being situated on opposite sides of the slant, as is most clearly shown in the half-diagonal section of the engine reproduced in Fig. 5, on page 429. A vertical longitudinal section of the engine is given in Fig. 6, on the same page, and Figs. 7 and 8, on page 432, are a transverse section through the centre of the engine and an elevation of the front end, respectively.

Referring first to Fig. 6, it will be seen that the engine consists of two main castings, of which the front one, *i.e.*, that on the left of Fig. 6, contains four cylinders, while the rear one contains four cylinders and also forms the chamber in which the slant works. The two castings are bolted together as indicated in Fig. 6, alignment being ensured by means of two dowel pins and two fitted bolts. The opposing cylinder bores are ground in one operation after the castings have been assembled in their normal position. The cylinder heads, in which the valves are situated, are formed of separate castings made in twin units, and light aluminium castings are attached to the heads to cover the valve gear, as shown in Fig. 5.

The pistons are each 5·312 in. in diameter and have a stroke of 3·51 in., giving a total displacement of 242 cub. in., or just under 4 litres, which is the same as that of the six-cylinder engine of the Buick car. These dimensions, it may be mentioned, were chosen to facilitate comparisons of size, weight and performance between the crankless engine and an engine of normal design representing good average practice. The compression ratio in the crankless engine is 5 : 1. The design and construction of the piston units can be followed by examining Fig. 5 in conjunction with the photographic illustration, Fig. 4, annexed. The pistons consist of stout aluminium castings, each pair being connected by a cast-steel yoke which embraces the rim of the slant. The yoke carries two bronze cups which form spherical seatings for the two ball-backed slippers used to transmit the force of the explosions to the face of the slant. The slippers, which are faced with white metal, are segmental in plan, as indicated in Fig. 7, and, in accordance with the well-known Michell principle, are pivoted assymmetrically so that they set themselves at a small angle with the face of the slant when the engine is running. A screwed plug fitted in the forward end of the yoke provides a means for adjusting the clearance between the pads and the slant to the normal amount, which is about 0·005 in. The ball-backed slippers are provided with a "tail" which fits in a slot in the steel yoke connecting the two pistons, to prevent any tendency of the slippers to rotate. A small bronze slipper is also provided to run on the periphery of the slant, its object being to prevent any tendency for the pistons to rotate; a light leaf spring is employed to keep the slipper in contact with the edge of the slant. The total weight of each reciprocating unit is 7¼ lb., which is equivalent to a weight of 0·42 lb. per square inch of piston area, a figure which compares very favourably with the corresponding one for a motor-car engine of orthodox design.

The slant, which takes the place of the crankshaft and connecting rods of an ordinary petrol engine, is a steel forging, 10 in. in diameter, $2\frac{7}{16}$ in. in thickness (measured axially) and weighing 40 lb.; the two faces make an angle of 22½ deg. with the axis. To secure the perfect dynamical balance that constitutes one of the essential features of the engine, it is necessary, as mentioned above, for a definite relationship to exist between the mass of the oscillating parts and the mass and dimensions of the slant. This condition is satisfied when the mass of the oblique portion of the slant, *i.e.*, the portion outside the boss, is equal to $2\,n\,m\,R^2/(A^2 + a^2)$, where n is the number and m the mass of each of the pistons with its attachments, A is the radius of the outer surface of the slant measured normally to the axis, a is the radius of the boss of the slant, and R is the distance between the axis of the slant and that of one of the pistons. The mass of the slant can be adjusted, *cæteris paribus*, by varying its axial thickness, and in the case of the engine we have inspected, this was made about 0·023 in. too small owing to an error in machining which could not be rectified in the time available. In spite of this defect, however, the engine ran at speeds ranging from 200 r.p.m. to 3,000 r.p.m., with little or no vibration.

As will be clear from Fig. 5, the slant is located on the shaft by means of coned washers and drives the shaft by means of straight-sided splines. The main shaft, which is 17 in. long and varies in steps from 1½ in. to 1⅝ in. in diameter, runs in three Skefko ball bearings, and power would be taken from the rear end to a separate clutch and gear-box through a short stiff shaft with universal couplings at each end. The axial thrust on the main shaft is taken on a double-acting Michell thrust block shown in section in both Figs. 5 and 6, the latter figure illustrating the method of securing the centre plate of the thrust block to the rear main casting of the engine. In connection with this bearing it should be noted that the distance between the two working surfaces is a minimum, so that the running clearance is practically unaffected by the expansion and contraction of the main shaft, due to temperature changes in working. Forward of the main shaft, and in line with it, is an auxiliary shaft to which the starting handle is attached and which also carries one of a pair of mitre wheels driving the valve gear, &c. The auxiliary shaft, as shown in Figs. 5 and 6, is connected to the main shaft by means of a dog clutch which serves to protect the mitre wheels from the effects of any longitudinal vibrations in the main shaft.

To follow the valve mechanism of the engine, reference should be made to Figs. 6, 7 and 8. From the first-mentioned of these it will be seen that the mitre wheels, above referred to, drive a short vertical shaft, the lower end of which carries a pinion engaging with a large idler spur wheel rotating in a horizontal plane in the bottom of the slant case. Two vertical camshafts, one situated on each side of the slant case, as shown in Fig. 7, are driven from the idler wheel by pinions secured to their lower ends by Woodruff keys. There are four cams on each camshaft, each cam operating one of the valves of two opposite cylinders through horizontal pusher rods and rockers; the latter are clearly

THE MICHELL CRANKLESS MOTOR-CAR ENGINE.

Fig. 5. APPROXIMATE HALF DIAGONAL SECTION SHOWING PISTON CONSTRUCTION & VALVES.

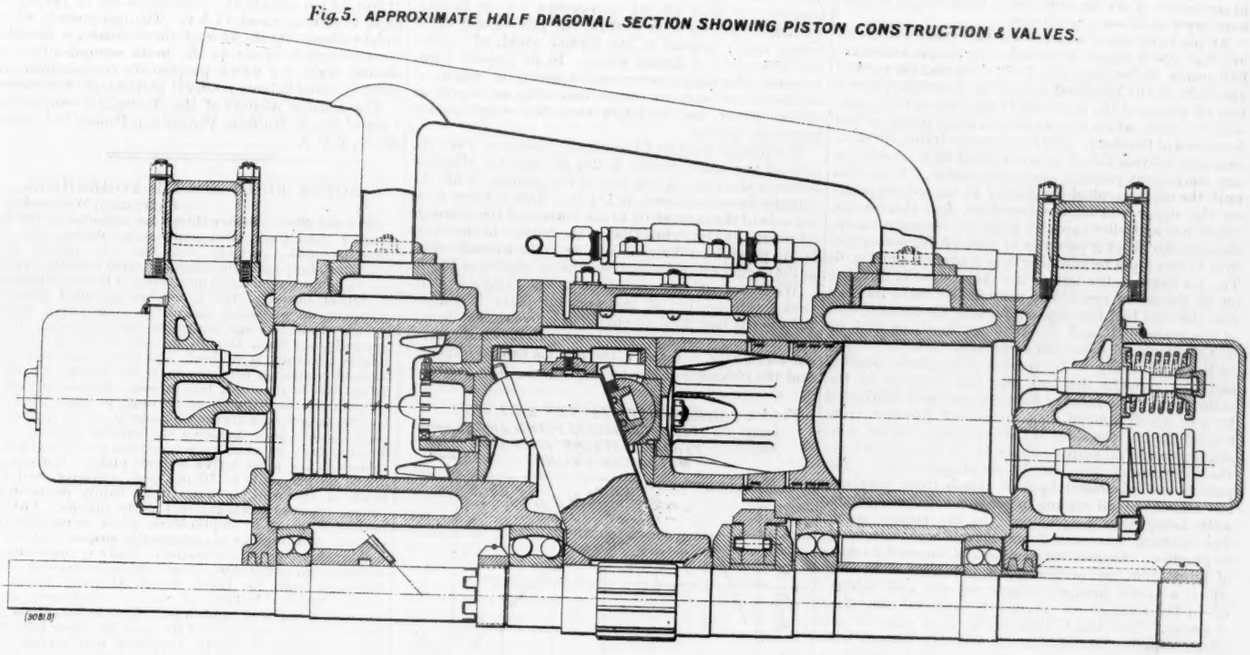
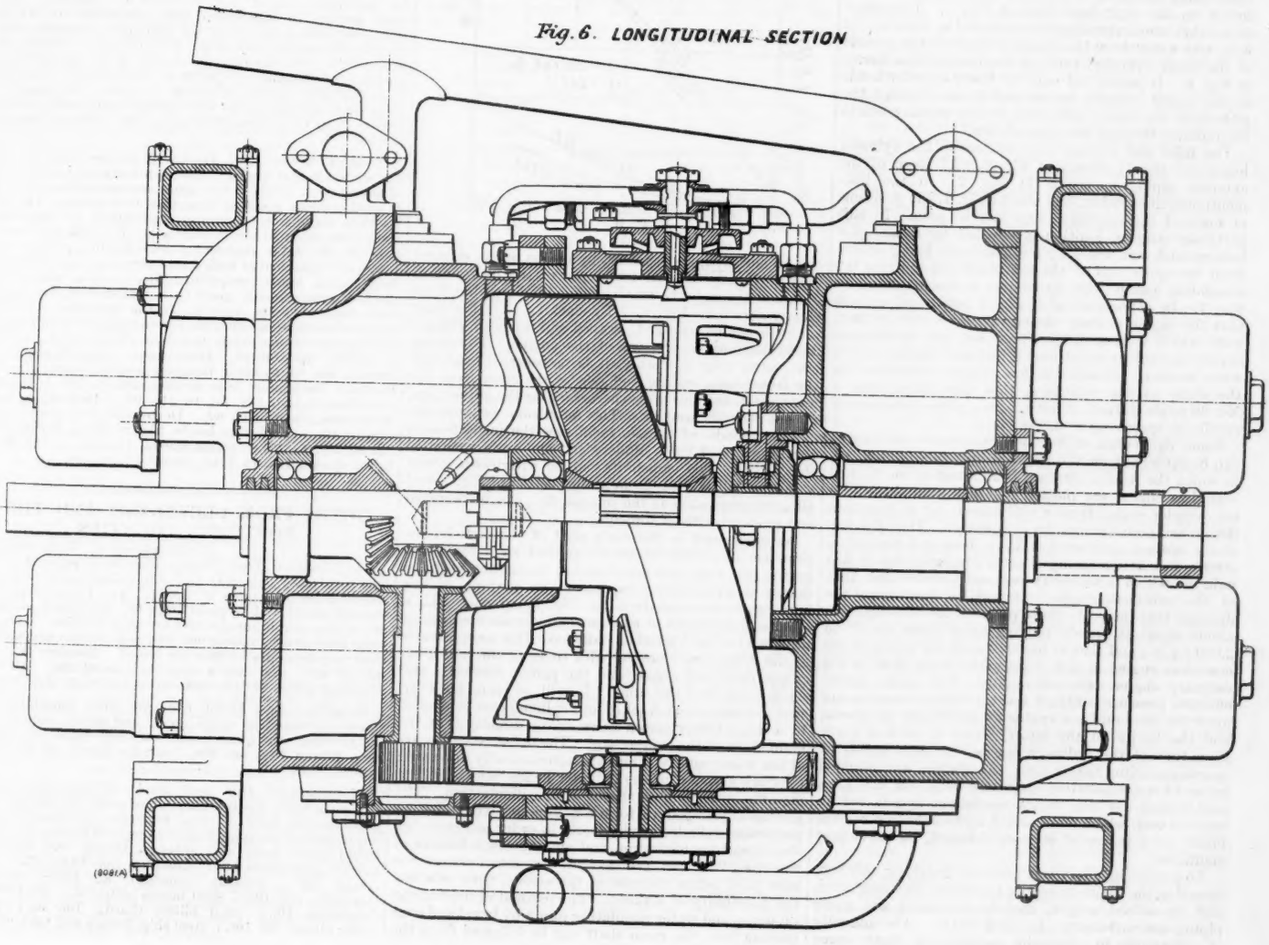


Fig. 6. LONGITUDINAL SECTION



shown in Fig. 8. The timing, which can be adjusted by means of the dog clutch and mitre wheels on the auxiliary shaft, is arranged so that the cylinders fire in succession at 90 deg. intervals; there are, of course, four impulses in each revolution.

Ample lubrication, which is an important feature in any high speed engine, is provided by simple and effective means. Reference to Fig. 7 will show that the vertical camshaft on the left-hand side of the illustration drives two oil pumps of the gear-wheel type, one at the upper, and the other, which acts as the scavenge pump, at the lower end of the shaft. The lower pump drains the slant case and delivers the oil to an external tank situated in any convenient position above the engine. From this tank the oil is supplied by gravity to the second pump on the upper end of the camshaft, and this pump, which has a smaller capacity than the scavenge pump, delivers the oil at a pressure of about 5 lb. per square inch to two pipes terminating in jets as shown in Fig. 6. The jet towards the left of the illustration is directed on to the mitre gears, but the oil also finds its way into the two ball bearings supporting the forward end of the main shaft and the auxiliary shaft, as well as to the gearing driving the camshafts. The other jet, on the right of Fig. 6, delivers oil to the thrust bearing and also supplies the two rear ball bearings of the main shaft. The faces of the slant are both lubricated by jets which emerge in a horizontal direction from holes drilled in the sides of the two pipes, and the camshafts receive an ample supply of oil thrown off from the periphery of the slant by centrifugal action. The pistons are lubricated by side splash from the slant, the amount of oil coming in contact with the cylinder walls being thus proportional to the engine speed. This method has been found simple and automatic in practice. Another interesting and successful means of lubrication, we may mention, has been evolved in which a small plunger compresses air and delivers oil in the form of an atomised spray to the slant chamber. The slant thus works in a mist of oil, which supplies the slant faces and the pistons with the necessary lubricant. This method has been developed for compressors, and is under consideration for prime movers.

The cooling water is circulated by means of a centrifugal pump driven from the lower end of the camshaft shown on the right-hand side of Fig. 7. The water jackets in the main castings are separated by a horizontal web, and water from the pump first enters the jackets of the lower cylinders through the connections shown in Fig. 6. It passes out over the lower cylinder heads to the upper cylinder heads, and thence through the jackets of the upper cylinders, finally passing out to the radiator through the pipes shown.

The inlet and exhaust connections to the cylinder heads are clearly shown in Fig. 6, and some of the external piping is visible in Fig. 2. In the last-mentioned illustration, and also in Fig. 1, the positions of some of the sparking plugs can be seen. In this particular engine, ignition is effected by means of a battery and coil, the ignition distributor being driven from the upper end of the camshaft which drives the circulating pump; the distributor is clearly shown in Fig. 7. In connection with Fig. 1, we should explain that the engine is there shown with two carburettors, with which it was at first provided, one carburettor supplying each group of four cylinders. Better results were, however, obtained with a single carburettor for the whole of the cylinders, that now fitted being a No. 36 triple diffuser Zenith, which gives satisfactory results at speeds up to 3,000 r.p.m.

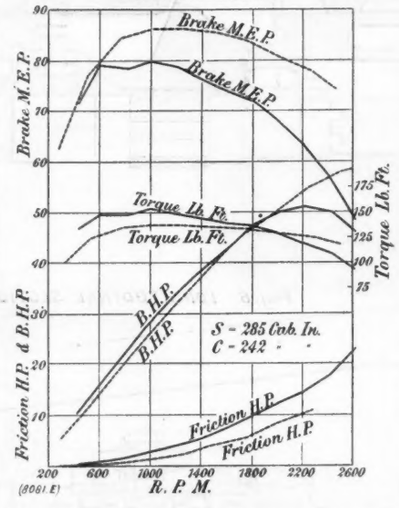
Some particulars of the performance of the engine can be gathered from the diagram reproduced in Fig. 10, in which the results obtained from a test of the Michell crankless engine are plotted together with those of a six-cylinder engine from a well-known car of American design and manufacture, for comparison. The cylinders of the latter engine were of 3½ in. bore and the piston stroke was 5 in., giving a total displacement of 285 cub. in., which is nearly 18 per cent. greater than that of the crankless engine. It will be seen from the diagram that the brake-horse power of the two engines is about equal at speeds ranging from 1,600 r.p.m. to 2,000 r.p.m., and that at higher speeds the power of the crankless engine is well maintained while that of the ordinary engine falls off rapidly. The brake mean-effective pressure is higher and the friction horse-power lower for the crankless engine at practically all speeds, and the torque of the latter, which is at first lower than that of the ordinary engine, becomes higher at speeds exceeding 2,000 r.p.m. As this test was intended to be of a comparative character only, the crankless engine was not run at its maximum speed, but in another test, which was carried up to 3,000 r.p.m., the brake horse-power of 60 was obtained, as previously mentioned.

No particular effort was made in designing and constructing the engine to reduce the weight to a minimum, and its actual weight, including exhaust and water piping and carburettor, is about 500 lb. The difficulty of obtaining in Australia satisfactory light cored castings, such as the cylinder blocks, will be readily appreciated, and it is considered that the weight of the two main castings could be reduced by about 35 lb. under better production conditions. It may also be pointed out that all the accessories are of bronze, aluminium having been used for the pistons and valve covers only; several of the former could, of course, be constructed of lighter alloys. In its present form, however, the engine represents a saving in weight of about 25 per cent. in comparison with an engine of similar power, and in larger sizes the weight-saving would be greater.

The overall length of the engine, measured over the nuts of the valve covers, is 28½ in., and the distance between the ends of the two main castings, with the cylinder heads removed, is 17⅛ in. The distance from the axis of the main shaft to the bottom of the scavenge oil pump is 8⅞ in., while that to the bottom of the circulating pump inlet flange is 10 7/16 in.; the average width of the engine, exclusive of the exhaust piping, is 15½ in.

With regard to accessibility, the makers claim that the inspection of the working parts is simpler than is the case with an engine of conventional design. By removing a cover provided on top of the slant case, as shown in Figs. 5, 6 and 7, the pistons can be inspected and the clearance of the pads checked. The clearance

Fig. 10. COMPARATIVE TESTS OF 8 CYL. 3·312" BORE × 3·5" STROKE CRANKLESS PETROL ENGINE ----- AND 6 CYL. 3½" BORE × 5" STROKE AMERICAN MOTOR CAR ENGINE ——



can be adjusted, if necessary, by means of the screwed plug previously referred to, access to the latter being obtained through the lantern holes in the piston most clearly shown in Fig. 4. By slacking back the plug, the pads can be removed, scraped and replaced without disturbing any other parts of the engine. To remove the piston yoke assembly, it is necessary to take off the front main casting and release the slant from the main shaft, and this is also necessary for the adjustment of the thrust bearing. The provision of separate cylinder heads, of course, facilitates the inspection of the interiors of the cylinders and the examination of the valves. The camshafts can be withdrawn downwards, as will be clear from an inspection of Fig. 7, and all accessories such as the pumps, &c., can be removed and replaced without difficulty.

As mentioned in the early part of this article, the principle described above, as applied to a motor-car engine, has also been developed in connection with the design of air compressors, and as an example of this application we reproduce, in Fig. 9, on page 432, a longitudinal section of an eight-cylinder air compressor designed for the Victorian Railways. The main features of the design are identical with those of the motor-car engine described above, and the piston diameters and strokes are also the same. It will be seen, however, that the inlets to each set of four cylinders are controlled by a single rotary piston valve driven directly from the main shaft of the compressor. The delivery valves are of the mushroom type and are automatically operated; they are situated in the cylinder heads, which project into the cylinders, as shown in the illustration. The pistons are shaped to form a bell-mouth which fits the projecting cylinder heads closely in order to reduce the clearance to a minimum, and an important feature of the design is that the toe of the piston covers the inlet port before the end of the stroke, thus reducing the possibility of leakage. The method of driving the oil pump and water circulating pump by bevel and spur gearing from the main shaft can be followed from the drawing without explanation. The compressor is driven directly by an electric motor through the flexible coupling shown, and is intended to run at 750 r.p.m. At this speed it can deliver 80 cub. ft. of free air per minute at a pressure of 100 lb. per square inch, absorbing about 17 h.p. The compressor, which weighs about 500 lb. without the bedplate, is intended for the supply of air to the brake equipment of an electric train, for which purpose its compactness and good dynamic balance render it particularly well suited.

The London address of the Australian company is: Care of Mr. E. Habben, Palmerston House, Old Broad-street, E.C. 2.

NOTES FROM SOUTH YORKSHIRE.

Sheffield, Wednesday.

Iron and Steel.—Better things are expected of the new quarter than have been experienced during the past three months. Already inquiries are rather more numerous, both on engineering and steel-making account, and although only a small proportion of these are resulting in actual business, the quantities specified generally represent an increased magnitude over those covered by the small-tonnage contracts just expiring. Prices generally are firm, though in one or two sections an erratic tendency is noticed. So far as raw and semi-finished materials are concerned no change in official quotations is reported, but in some directions cheaper supplies are anticipated as a result of coke producers having agreed to a further concession of 2*s.* per ton on blast furnace coke, bringing the current price at ovens down to 24*s.* Steel manufacturers are quietly optimistic, though in the most active sections plant is not engaged above 65 per cent. to 70 per cent. capacity, and then much of the work in hand is at barely remunerative prices. Special steels are still in the dumps. Virtually nothing is going to shipbuilders, whose requirements of castings and forgings are practically suspended until the boilermakers' dispute is settled. Railway materials still comprise an active line, tyres, axles, stores and wheels being on order for India, South America, Egypt and South Africa. Makers of heavy machinery report somewhat brighter conditions. New business has been booked in gas and oil-fired furnaces for home industries, while collieries in South Yorkshire and several other mining areas have ordered patent gear haulage drums. Toolmakers would do much better if war surpluses were not constantly reappearing. After the last of these has apparently been seen, substantial tonnages are discovered and put on the market at prices with which it is impossible for manufacturers of new products to compete. The same applies to high-speed steel, quantities of which have been sold as low as 6*d.* per pound as compared with the current market price of 3*s.* The condition of the mark apparently gives no real indication of the prospective measure of German competition. Despatches received from Sheffield agents in South America, for instance, show that German houses are offering considerably longer credits than their competitors, and are carrying heavier stocks.

South Yorkshire Coal Trade.—A general advance of 1*s.* per ton is this week notified in pit prices of all classes of house coal. This is the usual seasonal advance, and is neither more nor less than was anticipated. Housholders have not taken the opportunity of comparatively low rates to get in winter stocks, with the result that in the later months a considerable pressure of business is anticipated both on country and town account. Best steam hards comprise a firm section with Continental requirements more than maintained and home industrial demands slightly on the increase. Colliery stocks of cobbles and nuts have been reduced by improved trading conditions, while the demand for coking slacks is steadily maintained. Quotations:—Best handpicked branch, 30*s.* 6*d.* to 32*s.*; Barnsley best Silkstone, 27*s.* 6*d.* to 29*s.*; Derbyshire best brights, 26*s.* to 28*s.*; Derbyshire best house, 23*s.* 6*d.* to 24*s.* 6*d.*; Derbyshire best large nuts, 20*s.* to 21*s.* 6*d.*; Derbyshire best small nuts, 15*s.* to 16*s.*; Yorkshire hards, 21*s.* to 23*s.*; Derbyshire hards, 20*s.* to 22*s.*; rough slacks, 11*s.* 6*d.* to 13*s.* 6*d.*; nutty slacks, 10*s.* to 12*s.*; smalls, 7*s.* to 9*s.*

NOTES FROM CLEVELAND AND THE NORTHERN COUNTIES.

Middlesbrough, Wednesday.

The Cleveland Iron Trade.—Cleveland pig-iron is in only moderate demand, and the limited production is still slightly in excess of needs. No. 1 continues extremely scarce and keeps at 102*s.* 6*d.*, but other qualities are in very ample supply, and are easy in price. Though some makers are holding out for more, buyers can satisfy their requirements at 96*s.* for No. 3. Foundry 4 is on sale at 91*s.*, and No. 4 forge is quoted 88*s.* All the foregoing prices are for early f.o.t. and f.o.b. delivery.

Hematite.—East Coast hematite fully maintains its value. Demand is quite good, and some makers are not pressing sales quite so much as they did a little while ago. Mixed Nos. are 99*s.*, both for home use and for export trade.

Manufactured Iron and Steel.—Whilst business is still on a scale vastly below what could be desired it is gratifying to hear of some expansion in demand, the improvement being noticeable as regards billets, constructional steel, rails and sheets. Among the principal market quotations are:—Common iron bars, 12*l.*; iron rivets, 14*l.*; packing (parallel), 8*l.* 10*s.*; packing (tapered), 11*l.* 10*s.*; steel billets (soft), 9*l.*; steel billets (medium), 10*l.*; steel billets (hard), 10*l.* 5*s.*; steel boiler plates, 13*l.* 10*s.*; steel ship, bridge and tank plates,

9*l.* 15*s.*; steel angles, joists, and heavy rails, 9*l.* 10*s.*; fish plates, 12*l.* 10*s.*; black sheets, 15*l.*; and galvanised corrugated sheets (24-in. gauge, in bundles), 19*l.* 5*s.*

Imports of Iron and Steel.—Returns just issued by the Tees Conservancy Commission show the quantities of iron and steel unshipped at the Tees ports from Holland, Belgium, France, Norway, Sweden, Germany, and coastwise for the eleven months ending September 30 last, as compared with the same time a year ago, and the corresponding pre-war period of 1913–14. Pig-iron imported in the past eleven months amounted to 12,534 tons, as against 34,651 tons a year ago and 1,427 tons in 1913-14. Crude sheet bars, billets, blooms and slabs, unloaded during the period just ended, reached 66,526 tons, as against 50,264 tons a year ago and 33,655 tons in the months of 1913–14. Plates, bars, angles, rails, sheets and joists brought in to the end of last month totalled 10,842 tons, as against 6,111 tons a year ago and 19,481 tons for the corresponding months of 1913–14.

Shipments of Iron and Steel.—Official returns give the total shipments of iron and steel from the Tees last month at 98,670 tons, composed of 34,827 tons of pig-iron, 1,973 tons of manufactured iron, and 61,870 tons of steel. The figures as regards pig-iron were about the same as for the previous month, but clearances of steel were the heaviest of any month for nine years. Scotland was the largest customer for pig-iron, taking 4,220 tons; Sweden being next with 4,067 tons; then Germany, 3,983 tons, Wales, 3,210 tons; United States, 3,200 tons; Belgium, 2,603 tons; Danzig, 2,125 tons; Italy, 1,800 tons; Norway, 1,205 tons; and Switzerland, 1,200 tons. India was again the largest buyer of both manufactured iron and steel, importing 623 tons, of the former and 19,466 tons of the latter. Other principal receivers of steel were: Egypt, 5,011 tons Nigeria, 4,690 tons; Danzig, 2,533 tons; New South Wales, 2,205 tons; Natal, 2,172 tons; Japan, 1,843 tons; Hong Kong, 1,573 tons; Victoria, 1,571 tons; and New Zealand, 1,382 tons.

NOTES FROM THE SOUTH-WEST.

CARDIFF, Wednesday.

The Coal Trade.—Exports of coal as cargo from South Wales are maintained at a satisfactory level notwithstanding the apparent inactivity of business on the open market and the steadily declining prices realised for most classes of coal. Last week shipments were made to the extent of 557,940 tons, of which 318,190 tons went from Cardiff, 88,480 tons from Newport, 84,730 tons from Swansea, 55,770 tons from Port Talbot and 10,770 tons from Llanelly and Burryport. The total compares with 587,660 tons a week earlier and 577,850 tons a fortnight ago. Exports to France amounted to 186,560 tons, compared with 199,000 tons, Italy 86,350 tons against 104,720 tons, Argentina 37,900 tons against 53,200 tons, Spain 18,950 tons against 14,200 tons, Belgium 22,930 tons against 16,050 tons, Brazil 24,360 tons against 5,000 tons, and United States of America 10,750 tons against 14,200 tons. Shipment conditions have been adversely affected by the bad weather, which has delayed the arrival of expected tonnage and dislocated the arrangements of exporters and colliery owners. At some docks loading berths have been idle, but at others there has been a waiting list of steamers. Much of the coal being shipped abroad is on contract account, and new orders are none too plentiful. Coupled with this is the fact that the weekly rate of production continues at over 1,000,000 tons, and in consequence sellers are finding difficulty in securing customers to absorb outputs. Consequently prices generally are easy and irregular, as they are dependent on individual circumstances. Some collieries are fairly well placed in regard to orders and shipping, and naturally hold out for top values, but the majority are in need of orders, particularly those giving immediate shipment, and buyers able to take advantage of the opportunity can secure substantial concessions. Nominally, best Admiralty large is quoted at 28*s.* and seconds at 27*s.* 6*d.*, but for quick loading, supplies are freely offered at 1*s.* 6*d.* to 2*s.* less. Monmouthshires range from 24*s.* to 27*s.*, but for spot delivery are available at less. Drys, too, are weaker on the basis of 26*s.* 6*d.* to 27*s.* 6*d.* Smalls of all classes, with the exception of coking descriptions and washed duff, are in ample supply, with inferiors down as low as 13*s.* and best bunkers up to 18*s.*, but coking sorts still command 20*s.* to 21*s.*, and washed duff 24*s.* to 25*s.* There is a rather improved inquiry for cokes, and furnace sorts are now round 40*s.*, with foundry up to 45*s.* Pitwood has weakened considerably owing to increased arrivals of Portuguese timber which now realises only 27*s.*, compared with 30*s.* a week ago, while half-and-half French wood is down to 27*s.* 6*d.* against 31*s.* 6*d.*

Iron and Steel.—Exports of iron and steel goods last week amounted to 22,647 tons, which represents a considerable expansion on recent shipments. Exports of tin and terne plates amounted to 10,419 tons, compared with 4,767 tons, black plates and sheets, to 2,201 tons against 365 tons, galvanised sheets to 2,259 tons against 1,858 tons, and other iron and steel goods to 7,768 tons against 954 tons.

RECONSTRUCTION OF THE PORT OF YOKOHAMA.—His Majesty's Charge d'Affaires at Tokio reported on September 25 that the Japanese Minister of Foreign Affairs had stated that it was decided to reconstruct Yokohama as a port. The work is to start immediately, and it is hoped that by the end of the month some of the ordinary port facilities will be re-established. Meanwhile arrangements have been made to deal with the congestion which has been created, by diverting vessels to Kobé. The general situation is improving.

NOTES FROM THE NORTH.

GLASGOW, Wednesday.

Scottish Steel Trade.—There has again to be reported no change as having taken place in the steel trade of Scotland over the past week. Inquiries show some improvement, but the general demand is as poor as ever. The shipbuilding returns for the month of September give an idea of how little steel material has recently been requisitioned for that industry, and unless the difference with the boilermakers' society gets settled through the present negotiations we will probably have to look forward to a very black time this winter. Structural material has been moving fairly well of late, and in the black-sheet trade a healthy demand continues to exist for light sheets for abroad. The heavier gauges are still slow of sale, and home consumers are specifying for very little of this kind. The anticipated demand from Japan has not yet materialised. Overall the steel trade is not in a very healthy state at present and there are no signs of any immediate improvement. Prices are without change and are as follow:—Boiler plates, 13*l.* per ton; ship plates, 10*l.* per ton; sections, 9*l.* 15*s.* per ton; and sheets, 12*l.* 10*s.* per ton, all delivered Glasgow stations.

Malleable Iron Trade.—The demand for bar iron continues of the smallest, and the malleable iron makers in the West of Scotland are hard put to it to keep their works moving. There is not much inquiry this week, and the prospects are anything but reassuring. Prices show no alteration, and "Crown" bars are quoted firm at 12*l.* per ton delivered Glasgow stations.

Scottish Pig-Iron Trade.—There is still a big dearth of fresh business in Scottish pig-iron, and stocks are once again accumulating. Makers are hopeful of an early termination of the shipyard trouble which is causing the present absence of home demand because most of what is doing now is mainly on export account, and even that branch is very quiet. Prices are steady and are as follow:—Hematite, 5*l.* 5*s.* per ton delivered at the steel works; foundry iron No. 1, 5*l.* 5*s.* per ton, and No. 3, 5*l.* per ton, both on trucks at makers' yards.

Scottish Pig-Iron Shipments.—The shipment of Scottish pig-iron from Glasgow Harbour for the week ending last Saturday, September 29, amounted to 1,355 tons. Of that total, 1,170 tons went foreign and 185 tons went coastwise. For the corresponding week of last year the figures were 783 tons foreign and 79 tons coastwise, making a total shipment of 862 tons.

Shipbuilding.—The shipbuilding returns for the past month exhibit very clearly the low state of the industry throughout the country, and the total output from the districts only equalled the tonnage of one liner. The figures were:—

	Vessels.	Tons.
The Clyde	13	6,946
The Forth	2	2,843
The Tay	1	1,500
The Dee and Moray Firth ...	—	—
Total	16	11,289

The Clyde output, while certainly better than that for either of the two preceding months, does not compare at all with any previous month of September for many long years, and it is to be hoped that the return will never again be similar. A year ago the figure was nearly 35,000 tons, which itself compared badly with the 77,000 tons of September, 1913. The total for the year to date is 155,222 tons, as against 289,218 tons for the same period of last year, 489,425 tons for 1920, and 488,180 tons for 1913—each for the first nine months. During the past month there were about half a dozen new vessels reported as having been placed, but even should the dispute with the boilermakers be settled there is so little work booked that it will be a long time before the shipbuilding trade gets round the corner.

Institution of Engineers and Shipbuilders in Scotland.—The opening meeting of the Institution of Engineers and Shipbuilders in Scotland for the session 1923–24 will take place in the Rankine Hall, 39, Elmbank-street, Glasgow, on the evening of Tuesday, October 16. The retiring president, Mr. Harold E. Yarrow, C.B.E., will be in the chair, and will introduce the new president, Mr. J. Howden Hume. A very interesting syllabus has been drawn up, and a list of the papers to be submitted during the session will be given next week.

TRADE CATALOGUES FOR THE WEST INDIES.—We understand that His Majesty's Trade Commissioner in the British West Indies, Mr. J. L. Wilson Goode, would be glad to receive for reference and for display in his office, copies of up-to-date catalogues of British productions to assist him in furthering British trade in the West Indies. Catalogues should be addressed to His Majesty's Trade Commissioner, 10 Broadway (P.O. Box 225), Port of Spain, Trinidad, and it should be noted that trade catalogues and advertising matter of no commercial value are admitted free of duty.

DUBLIN DOCKYARD.—When the Dublin Port and Docks Board met last Thursday a letter was read which intimated that the premises, plant and machinery of the Dublin Dockyard Company Limited had been sold as a going concern to Vickers (Ireland) Limited. Application was made to the Board for the necessary assignment to certain leases, which is to be given after certain formalities are completed. The directors of the purchasing concern are Mr. Douglas Vickers, Mr. J. F. Barr, Senator Moran, Mr. G. Ridgway, Commander Sir Trevor Dawson, Bart., Sir Vincent Caillard, Mr. Jeremiah McVeagh and Sir Henry Forde.

NOTICES OF MEETINGS.

THE JUNIOR INSTITUTION OF ENGINEERS.—Friday, October 5, at 39, Victoria-street, at 7.30 p.m. Lecturette, "Design of Underground Cable Systems," by Major A. M. Taylor, M.I.E.E. Friday, October 12, at 7.30 p.m., at 39, Victoria-street. Ordinary Meeting. Mr. W. Y. rath Lewis, M.I.Mech.E., will deliver a paper on the "Never Stop Railway." The chair will be taken by the president, Captain H. Riall Sankey, C.B., C.B.E., R.E. (retired). Saturday, October 13, at 2 p.m., visit to the works of the Gas Light and Coke Company, at Beckton.

THE DIESEL ENGINE USERS' ASSOCIATION.—Friday, October 5, at the Institution of Electrical Engineers, Savoy-place, Victoria Embankment, W.C. 2. Discussion on "Some Notes on a Broken Crankshaft and the Manner in which an Emergency Repair was carried out on a Diesel Engine in Barbadoes," and, if time permits, "Some Particulars of the Comparative Running Costs of Steam and Diesel Driven Pumping Plants in Alexandria, Egypt."

THE WEST YORKSHIRE METALLURGICAL SOCIETY.—Saturday, October 6, at 7 p.m., at the George Hotel, Huddersfield. Annual General Meeting.

THE BRADFORD ENGINEERING SOCIETY.—Monday, October 8, at 7.30 p.m., in the Hall of the Bradford Technical College, when Mr. Landor Baldwin will read his Presidential Address on "The Engineer's Place in Industry." Illustrated by lantern slides.

THE INSTITUTION OF HEATING AND VENTILATING ENGINEERS.—Tuesday, October 9, at 7 p.m., at Caxton Hall, Westminster, S.W. 1. Autumnal General Meeting. Joint Paper by Mr. P. M. B. Grenville and Mr. T. Moodie, M.I.Mech.E., on the "London County Hall: Facts, Figures, and Reflections."

THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.—Tuesday, October 9, at the House of the Royal Society of Arts, John-street, Adelphi, the following paper will be read, "Recent Research bearing upon the Origin of Petroleum," by Mr. E. H. Cunningham Craig, B.A., F.R.S.E., F.G.S., M.Inst.P.T. The chair will be taken at 5.30 p.m. by the President, Mr. H. Barringer.

THE INSTITUTION OF AUTOMOBILE ENGINEERS.—Wednesday, October 10, at 8 p.m., at the Royal Automobile Club, Pall Mall, S.W. 1. Presidential Address by Mr. H. G. Burford, on "Automobile Engineering as a Profession."

THE INSTITUTION OF ENGINEERS-IN-CHARGE.—Wednesday, October 10, at 7.30 p.m., at St. Bride Institute, Bride-lane, Fleet-street, the president elect, Mr. T. Cooper, M.A. (Cantab.), M.Inst.C.E., will deliver his address on "Engineering Records and their Value to the Engineer-in-Charge." The chair will be taken by the retiring President, Dr. Hele-Shaw.

SOCIÉTÉ DES INGENIEURS CIVILS DE FRANCE: BRITISH SECTION.—Wednesday, October 10, at 6 p.m., in the Lecture Theatre of the Institution of Electrical Engineers, Savoy-place, Victoria Embankment, W.C. 2. Ordinary Meeting. Mr. Roger T. Smith, B.Sc., will deliver his Presidential Address for the session 1923–24.

THE NORTHAMPTON ENGINEERING COLLEGE ENGINEERING SOCIETY.—Thursday, October 11, at 5.30 p.m., in Room 102, at Northampton Engineering College, St. John-street, E.C. 1. Presidential Address by Dr. R. M. Walmsley, F.R.S.E., M.I.E.E., and a paper on "Fatigue" by Mr. C. E. Larard, M.I.M.E.

THE NEWCOMEN SOCIETY.—Friday, October 26, at 5.30 p.m., in Prince Henry's Room, 17, Fleet-street, E.C. 4, when the President, Mr. L. St. L. Pendred, will deliver his Presidential Address on "The Value of the History of Technology."

UNIVERSITY OF LONDON, UNIVERSITY COLLEGE, ENGINEERING SCHOLARSHIP.—The Goldsmid Engineering Entrance Scholarship of the value of 40*l.* a year for three years at University College, London, has been awarded to Mr. C. Murray (Ealing County School). Mr. O. Moody (Central Foundation Boys' School) was placed *proxime accessit*.

"EXPERIMENTAL WIRELESS."—A new monthly paper bearing the title quoted above has just been added to the long list of publications devoted to wireless subjects already in existence. The majority of the latter, however, have sprung up during the last year or so, since the inception of regular broadcast programmes, and they cater mainly for the needs of persons in whom a somewhat superficial interest in wireless matters has been aroused by the new form of entertainment. *Experimental Wireless*, on the other hand, will be devoted entirely to the interests of the serious experimenter, and broadcasting news, elementary wireless theory, instructions for making simple sets, and reports of society meetings will be excluded from its columns. The first number of the new publication, now before us, contains articles on the maintenance of high-frequency oscillations by valves, the fading of signals, the use of neon lamps for wireless experiments, antenna constants, an Armstrong super-heterodyne receiver and other matters of interest to the genuine experimenter, and we have no doubt that if the standard reached in the first number is maintained in subsequent issues the publication will be highly appreciated by the class of person for whom it is intended A very useful feature which the publishers, Messrs. Percival Marshall and Co., 66, Farringdon-street, E.C. 4, have instituted in connection with the paper is an experimental wireless laboratory in which readers can have their apparatus calibrated free of charge. The price of the paper is 1*s.* net and is now on sale.

THE MICHELL CRANKLESS MOTOR-CAR ENGINE AND AIR COMPRESSOR.

Fig. 7. SECTION THROUGH SLANTCASE

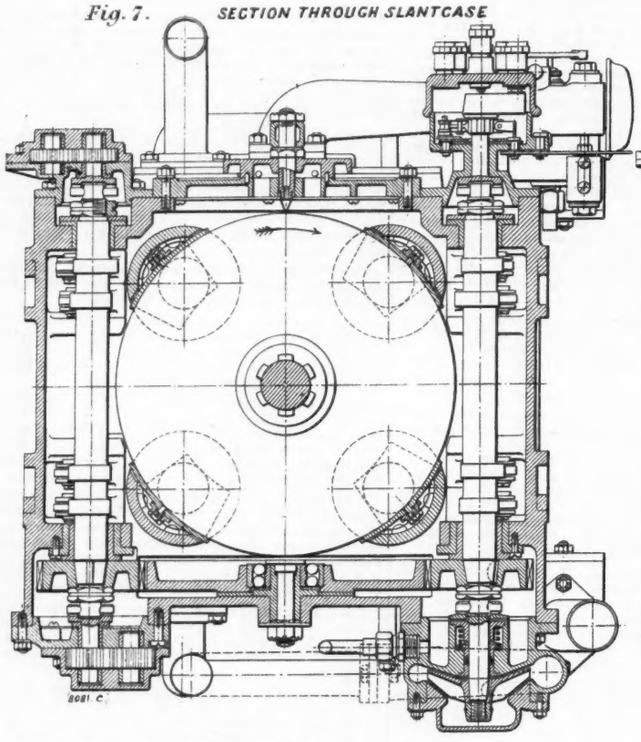
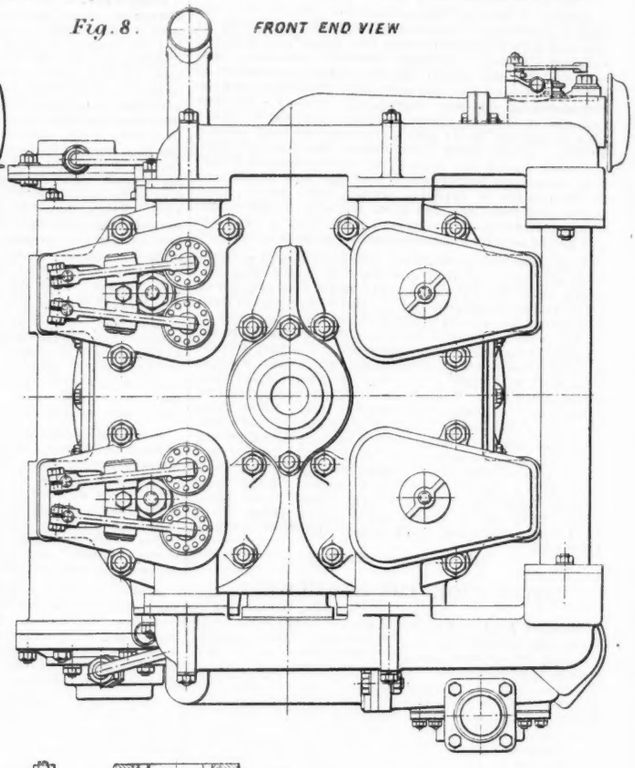


Fig. 8. FRONT END VIEW



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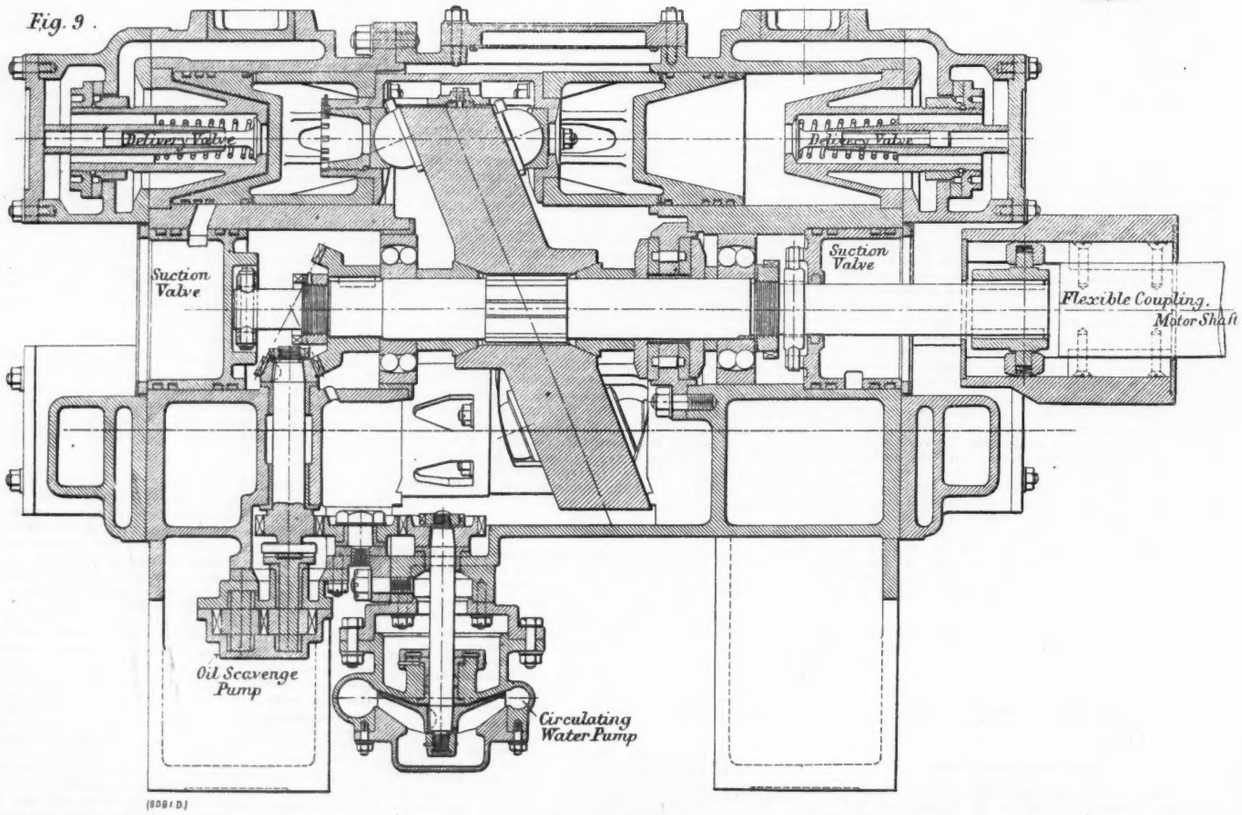

TRADE WITH INDIA.—Mr. T. M. Ainscough, H.M. Senior Trade Commissioner in India, is at present on an official visit to this country, and will be in attendance at the Department of Overseas Trade during October for the purpose of interviewing manufacturers and merchants regarding trade with India. Appointments must be made, and all correspondence relating to them should bear the reference 4814 T.G., and be addressed to the Comptroller-General, Department of Overseas Trade, 35, Old Queen-street, Westminster. We trust that manufacturers will avail themselves of this opportunity.

LECTURES ON MECHANICAL APPLIANCES IN THE BOILER HOUSE.—We are informed by Messrs. Ed. Bennis and Company, Limited, that they have a large number of lantern slides relating to stokers, coal and ash-handling plant, &c., available for loan for lecturing purposes. A booklet has been issued in connection with the scheme, and a copy can be obtained by any *bona fide* inquirer on application to them at the offices of the company 28, Victoria-street, London, S.W. 1.

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SHIP-BREAKING OPERATIONS AT THE YARD OF MESSRS. COX AND DANKS, LIMITED, QUEENBOROUGH, KENT.

(*For Description, see Page* 437.)

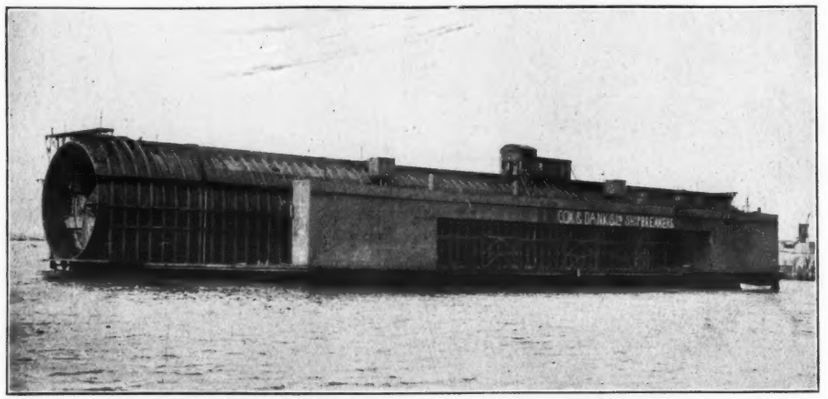

Fig. 1. German Floating Dock for Submarines: Side View.

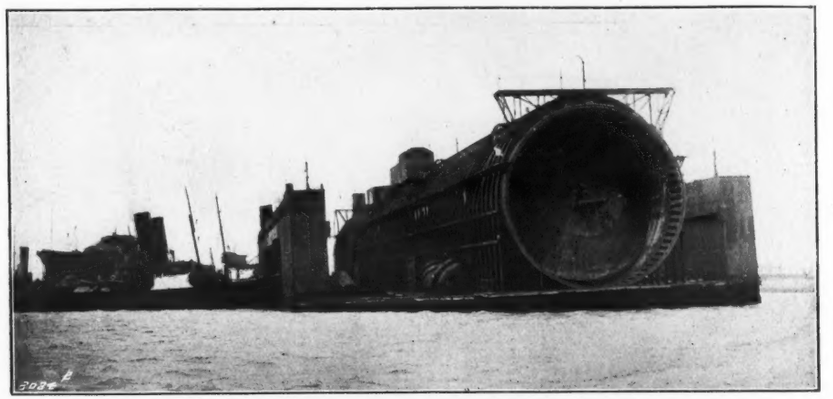

Fig. 2. German Floating Dock for Submarines: End View.

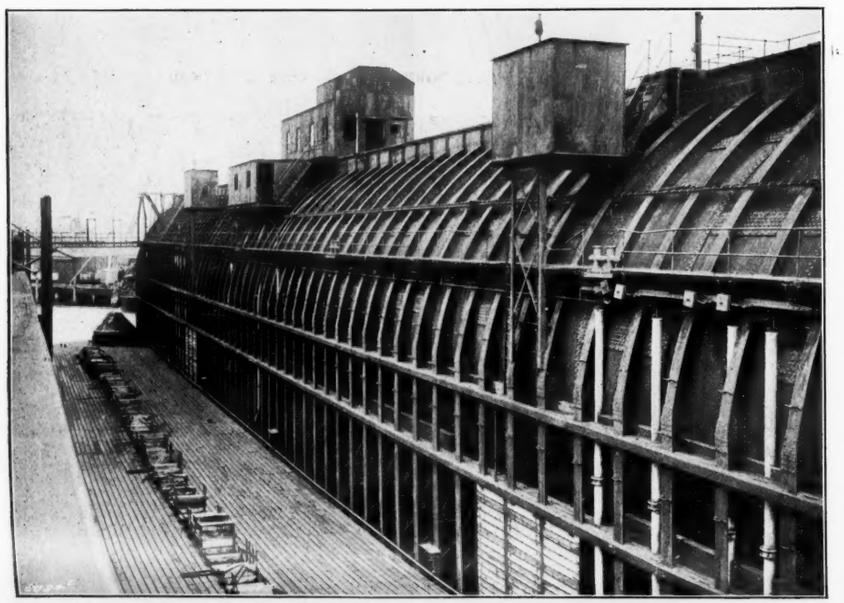

Fig. 3. German Floating Dock for Submarines: View showing Side-Berth and

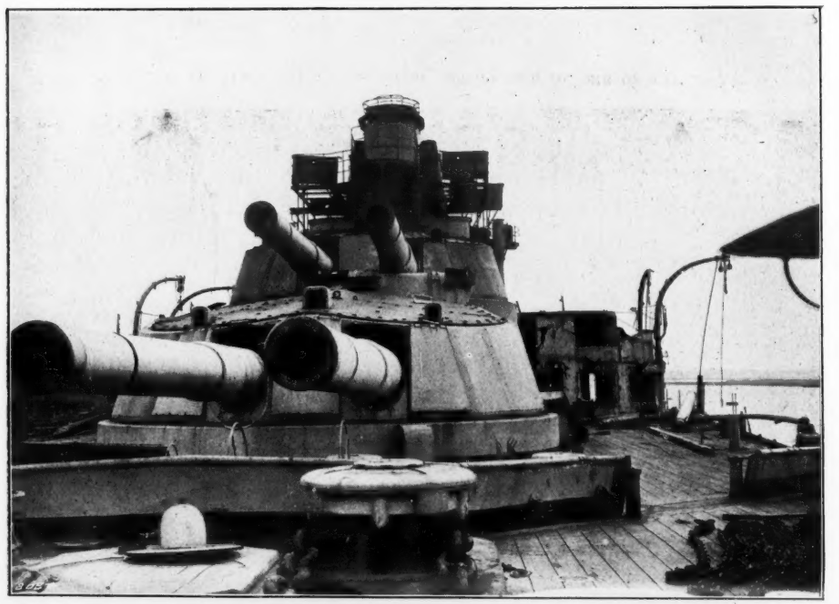

Fig. 4. The After-Turret of the "Orion" with 13·5-inch Guns Intact.

Fig. 3. German Floating Dock for Submarines: View showing Side-Berth and

Fig. 4. The After-Turret of the "Orion" with 13·5-inch Guns Intact.

Fig. 5. Forward Turret of the "Erin," with Guns Partly Demolished.

Fig. 6. Removing Half the Jacket from the Breech of one of the 13·5-inch Guns of the "Erin."

Fig. 7. 15-inch Armour Plate Showing Cut Surface.

Fig. 8. View from the "Erin," showing the "Orion" in the Background.

ENGINEERING.

Offices for Publication and Advertisements, 35 and 36, Bedford Street, Strand, London, W.C.2.

We desire to call the attention of our readers to the fact that the above is our SOLE ADDRESS, and that no connection exists between this Journal and any other publications bearing somewhat similar titles.

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ADVERTISEMENT RATES.

The charge for advertisements classified under the Headings of Appointments Open, Situations Wanted, Tenders, &c., is four shillings for the first four lines or under, and one shilling per line up to one inch. The line averages seven words. When an advertisement measures an inch or more the charge is 12*s.* per inch. Payment must accompany all orders for single advertisements, otherwise their insertion cannot be guaranteed. Terms for displayed advertisements on the wrapper and on the inside pages may be obtained on application. The pages are 12 in. deep and 9 in. wide, divisible into four columns of 2¼ in. in width. Serial advertisements will be inserted with all practicable regularity, but absolute regularity cannot be guaranteed.

TIME FOR RECEIPT OF ADVERTISEMENTS.

Advertisements intended for insertion in the current week's issue must be delivered not later than First Post on Thursday. In consequence of the necessity of going to press early with a portion of the edition, alterations for standing advertisements should be received on the Friday previous to the day of publication.

All accounts are payable to ENGINEERING, LTD. Cheques should be crossed "The National Provincial and Union Bank of England, Limited, Charing Cross Branch." Post-Office Orders should be made payable at Bedford-street, Strand, W.C. 2.

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TASMANIA: Gordon & Gotch Prop'ty, Ltd., Launceston: Hobart.

UNITED STATES: For Subscriptions, New York: W. H. Wiley, 432, Fourth Avenue. For Advertisements: J. S. Allan, 30, Church-street, New York.

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Two-Page Plate.—SHIP-BREAKING OPERATIONS AT THE YARD OF MESSRS. COX AND DANKS, LTD., QUEENBOROUGH, KENT.

DEATH.

SAMUEL PUPLETT, M.I.Mech.E., of 47, Victoria-street, Westminster, on September 30, 1923, at 99, King's Avenue, Clapham Park, in his seventy-ninth year.

ENGINEERING.

FRIDAY, OCTOBER 5, 1923.

INVENTION AND PRACTICE.

WHEN competent men are busy on industrial work they follow established practice, and are suspicious of whatever may disturb it. The more necessary it is to obtain the best results, the more sensitive the practical man is to such disturbances of practice as a new invention or method may suggest, and the more insistent that before it is allowed to intrude into practice, the new invention should either have reduced its interference with the custom and convenience of practice to a minimum, or have demonstrated very fully an advantage more then proportionate to the proposed disturbance. These considerations, with perhaps the less rational forces of indolence, inertia and prejudice, operate to sift the claims of new inventions and sometimes to delay their introduction. This has been by no means an unmixed evil. Stability is a first necessity of industrial practice, which becomes increasingly greater as the size and complexity of the industrial mechanism increases, and as the issues that turn on its success become graver. It has never been more necessary than it is to-day.

But though a tendency that prevents the interruption of practice is in itself conservative of industrial interests, and cannot safely be discarded without good reason, the history of more than a century has shown that the greatest advances in industrial practice and the greatest elements of progress in material well-being have arisen from abrupt disturbances of practice by invention. Any industry that depends, as in the present stress of international competition all industries depend, on the rate of its progress, and the extent to which it can keep abreast or ahead of its competitors in other countries, must find means to recognise or take the benefit of valuable inventions when they are made, without waiting till in the ordinary cycle of invention they are re-discovered perhaps twenty years later and in another country. The sense of this necessity to conciliate the maintenance of stable practice with the earliest possible adoption of whatever may make it more efficient is doubtless responsible for the institution of the Department of Scientific and Industrial Research, and for the remarkable strides that in the face of unexpected restriction of its relatively modest resources it has made in the few years of its existence. Scientific men who turn their abilities to industrial purposes without a knowledge of industrial practice are sometimes apt to regard themselves as missionaries to the ignorant industrial heathen. The intelligent industrial, on the other hand, who knows the difference between the artificially definite conditions and simplifying assumptions that are proper and even necessary in laboratory work and the more complex and less definable conditions that often are inevitable in practice, are equally correct and by no means less emphatic in recognising such scientific men as industrial savages, ignorant and contemptuous of inexorable industrial laws and necessary discipline, a standing danger to civilised industry. Much of the prospects of British industry depends on the extent to which scientific men can adopt industrial civilisation by recognising the supreme authority in industry of circumstances that as yet science cannot control, and industrial laymen can acquire the faith that their processes will prosper and progress only to such extent as they conform to the facts established by science, and at such rate as they adopt them into industrial practice.

Reflections such as these occur naturally when it is remembered that just about a century ago—some time in 1823—the first practical electric telegraph was publicly described, that the invention had been made and practically demonstrated in 1816—over twenty years before Cooke and Wheatstone's first patent—and that it was promptly rejected by the Admiralty on the ground that the semaphore answered all requirements, and that no electric system was necessary or could be entertained. The need for communication between distant points was clearly felt even in those days, when so little was available to satisfy it. At the cost of some 2,000*l.* a year the Admiralty maintained a system of semaphores between Whitehall and Portsmouth, though it was useless by night and in foggy weather, and involved men watching the distant semaphores all day on the chance of a message coming, which must have been a singularly monotonous and soul-destroying occupation.

The inventor of the proposed electric telegraph, Francis Ronald, was a young man 28 years old, who had been applying his scientific tastes and unusual powers of observation and experiment to obtaining a system that would work in practice. Not having facilities for running wires across country, he erected two tall and broad skeleton screens on a lawn at Hammersmith 20 yards apart, each having 19 horizontal bars. Each bar had 37 hooks, from which hung silken cords, and a thin iron wire was run backwards and forwards, supported and insulated by the silk, to a total length of rather more than 8 miles. This was a preliminary experiment, intended to confirm the belief that a current of static electricity, derived from a frictional machine or a Leyden jar, would pass instantaneously through such a length of wire, though Ronalds recognised that in suitable conditions a wire of sufficiently great length might be wholly discharged before the current had passed through it. In the present experiment Ronalds connected pith-ball electroscopes and "insulated inflammable air pistols" to each end of the wire, which was charged by a Leyden jar, and discharged by touching it with the hand and passing the shock on to the pistols. In every instance the divergence or collapse of the electroscope balls, the shock, and the explosion of the pistols appeared to occur simultaneously.

This experience having been repeated often enough to give assurance to the observers that it was a safe basis for the system, the method in contemplation could apparently have been applied forthwith with aerial conductors. As a fact the pith-ball electroscope was tried about a year or so ago on an aerial line between London and North Walsham with a 200 volt current derived from a Megger testing instrument. This worked satisfactorily when

the line was earthed momentarily at the sending end several times a minute.

Ronalds, however, had the feeling, which has been confirmed in modern practice, that it would be better for the line to be laid underground. Accordingly, he dug a trench 525 ft. long, made a wooden trough in it 2 in. by 2 in., with its surfaces well coated with pitch, and laid his wire in it through lengths of stout glass tube, connected by expansion joints of soft wax to provide against changes of temperature, the whole being covered with wood and pitch before the trench was filled in. To provide for accidental faults the wire was broken midway and brought to a conductor furnished with electroscopic pith balls, from which it could be disconnected on either side, so as to indicate in which half any fault lay; and the system was to have a series of such "proving stations." The energy was provided by 6 in. cylindrical frictional electrical machines at each end of the line, and the communication from one end of the wire to the other was started by electroscopes at each end, the wire being kept normally charged and the electroscope balls divergent, and the electroscopes collapsing simultaneously when the line was discharged from either end. The attention of the receiving station was attracted by a gas pistol through which the spark passed when the sender momentarily earthed the line, the receiver being able to disconnect the pistol when necessary. The communication was made by an arrangement curiously anticipating the Hughes printing telegraph. It consisted in fact of dials at each end of the line, bearing identical figures, letters, or other symbols, each dial being carried on the arbor of a clock beating exact seconds. The dial revolved behind a rotatable metal shutter in which a radial window was cut, just large enough to allow one sector of the dial containing one set of symbols to be visible. By agreement the sender's dial was always in a definite position—thus displaying a definite set of symbols—when the attention of the receiver was first called, and the receiver thereupon adjusted his dial to the same position. The sender then sent his message by discharging the line successively, as the symbol he wanted was displayed on his dial through the window, and as the clocks were both beating exact seconds they would be practically synchronous throughout the message, and each symbol sent would appear duly through the window of the dial at the receiving end.

The rejection of his invention did not sour Mr. Ronalds, but it made him abandon his electrical experiments, and delayed the introduction of electric telegraphy by over twenty years. How much practical experience was thus lost which might have been available when electric telegraphy was in fact established with the advantage of the discovery of the electro-magnet is not to be conjectured, but no doubt can be felt that, both in this respect and in the delay in superseding the cumbrous and unsatisfactory semaphore system, the loss must have been considerable. The remarkable qualities of the inventor as a resourceful and singularly open-minded experimenter were not indeed lost to science, for Mr. Ronalds became a Fellow of the Royal Society, and ultimately was appointed the first Director of the Kew Observatory. His case, moreover, was saved from one of the more painful circumstances of abortive inventions with genuine merit by his own evident sweetness of temper, which led him to receive the Admiralty's decision with "very little disappointment and not a shadow of resentment on the occasion, because every one knows that telegraphs have long been great bores at the Admiralty." He lived long enough too, for his contemporaries to remember his services in telegraphy, and he was knighted in 1870 for "his early and remarkable labours in telegraphic investigations." Only last year Sir Andrew Ogilvie, to whom the organisation of practical telegraphy and telephony is so much indebted, directed attention to the fact that, apart from his many experiments, Ronald's telegraph had definitely been proved to be a practicable instrument. To Ronalds and to his memory as much justice was done in the long run as was possible in the circumstances. The fate of his actual invention remains, however, a standing example of the danger to industry of the neglect of invention at the time at which it is made; and one of the most important functions of the Research Department is to promote such relations between science and industry as will minimise the risk of such neglect in the future, while safeguarding industry against the introduction of immature devices into established practice.

THE DESIGN OF SMALL MARINE MOTORS.

From the criticism to which the small marine motor of any power up to 100 h.p. has been recently subjected, it appears to have developed far more slowly and less satisfactorily than the automobile engine or the aircraft motor. According to the statements of Mr. A. F. Evans, the engineer of the Royal National Lifeboat Institution, it has taken nearly seventeen years to produce an engine capable of meeting the requirements of that important body, while the motor yacht owner who is compelled to adopt some one of the various commercial types of marine motors finds many difficulties in maintaining his engine in efficient working order. After many years of experience in maintaining and running motor-boat engines, Mr. Basil Joy has come to the conclusion that although the main parts of the engine are extraordinarily reliable, there remains the fear that some minor repair or adjustment may be required in bad weather or in a tideway when coming to moorings, and that a sense of security can only be provided by a twin-screw installation.

In the two papers on the design of small marine motors, read recently before the Marine Conference of the Institution of Automobile Engineers, much criticism was expended on the engines exhibited in the Shipping, Engineering and Machinery Exhibition from the points of view of the two authors, named above, it being alleged that even a fair measure of perfection is far from having been attained. In comparing the marine motor with the engine of the automobile it must be remembered, however, that the latter runs at low load for the greater part of the time, that the air drawn through the radiator helps to keep it cool, and that the parts liable to minor derangements or requiring occasional adjustment are usually so placed as to be fairly easy of access. The engine of the motor boat on the other hand must be protected from the wind, which is often charged with spray, and it is so built into the boat that the conditions under which it works are very different from those of the test bench. An engine which is easy to swing and start on a car becomes difficult when installed in a boat, even though fitted with a well-designed drive for cranking. There is one comfortable position in which to stand in order to deliver most power to the engine with least fatigue to the muscles, and this cannot be maintained on a deck which is rolling, or pitching, or both, because other forces have to be exerted to maintain the equilibrium of the body. Moreover, an engine that has stood for some time is always stiff to start, and generally more revolutions are required before an ignition is obtained than when the engine is in normal running condition. Electric self-starters are now very usual on motor cars, and should none of these be suitable for use on boats there is the alternative of the impulse starter, a type that is incorporated in the magnetos of large tractor engines.

The lifeboat engine can be compared fairly only with that of the fire engine; both are required for instant use under conditions of emergency and danger, and both are maintained and looked after in a manner impossible to attain under commercial conditions and impracticable under private ownership. The lifeboat is housed and protected, whereas the ordinary motor yacht remains afloat at her moorings in a permanently damp atmosphere, and the effect of this on the electric ignition details is one of the chief sources of minor troubles. It should not be impossible to design and produce electric apparatus that can be exposed to damp and sea water as well as to changes of temperature; the submarine cable, it is true, is not exposed to vibration or to much variation in temperature, but it transmits messages for years. The trolley of the electric tram also continues to conduct in rain, fog and snow; and electric motors are constructed capable of working pumps while immersed in water in mines. It has, however, been found necessary to get electric wires specially covered with ebonite for the lifeboat engine ignition and to use the low-tension system because its mechanical complication is considered a lesser evil than the unreliability of the high-tension magneto under the particular conditions. The problem of manufacturing satisfactory electrical details, however, should not be outside the range of knowledge of the electrical engineer. It would thus appear that commercialism is to blame, that the demand is small and that it is possible for a "good salesman" to sell articles for the marine motor boat engine that are actually being manufactured for and are only suitable for, other purposes.

When criticism is let loose on the marine motor the manufacturer is surprised because he "has heard no complaints." This is where he is handicapped. The automobile can be driven round to the works of its maker and one of those responsible for its design can be interviewed. We may write off the salesman absolutely from the point of view of the right information getting to the right destination. When a designer sees a car that has just been driven over and has a practical demonstration as to what is wrong, preferably at the expense of his own muscular power or inconvenience—the lesson is learnt thoroughly and its effect is produced in subsequent models. Of course, it occasionally happens that a car arrives with an overheated engine, and a glance inside the crank-case shows a blue-hot crankshaft long deprived of oil; or the removal of the radiator cap shows absence of water. The pent-up ire of the designer can then break loose, and he can ask the chauffeur whether he does not know that his engine frequently needs water and oil as well as petrol, and requires to be looked after with consideration. The motor-boat engine, however, cannot, in most cases, be brought to the manufacturers' works. When the owner, or whoever maintains the engine, overhauls it in search of old troubles renewed or new troubles developing, he has to get into awkward positions, positions in which sometimes he lies on the arm that has to do part of the work, under conditions that prevent his seeing what is happening because it is impossible to get hand and head into the same place at the same time, and so uncomfortable that he is liable to be seized with violent cramp just as success is within a few seconds of attainment. It is then that the complaint is made, but there is no dictaphone at hand to record it, and it is no good wiring it to the maker; the percentage left after it had been sufficiently bowdlerised for acceptance by the Post Office would be too small to be worth sending.

Both Mr. Evans and Mr. Joy are fully justified in bringing this subject of minor troubles into prominence, and the marine motor designer ought certainly to take account of the particular conditions under which his productions sleep as well as those under which they work. The aeronautical engine is cared for by a trained staff of ground men and air mechanics, and is housed, but the small marine motor is shut down and left—afloat.

It may be thought that the designer and draughtsman must have long since got out of touch with the shops when they are able to produce machines that are so awkward to maintain, but this is not necessarily the case. The draughtsman may lay a reduced scale tracing of his engine over a drawing of a boat, and he may use a sheet metal, jointed, side or front elevation of a man made to the same scale, in order to find out whether there is sufficient room for him, and whether and how parts can be reached; and yet trouble may exist because the parts that can be reached with one or both hands cannot be seen at the same time, or both hands cannot reach the part in such manner as to supply the required reaction to the force applied, a case that occurs frequently on small pipe fittings or controls.

The marine motor is only part of what should be considered as a single unit and constructed as such, that is a power unit comprising engine, clutch and reverse gear, with the thrust bearings complete, to which the tail shaft and propeller can be coupled. The power unit should include everything essential to the running, the petrol tank, the carburettor, the controls and the starting gear, the oil pump for emptying the crank-case, and the water pump, the ignition and the exhaust. It should comprise a by-pass so that the engine temperature can be

maintained in cold weather, while drain cocks should be placed so that the jackets can be emptied while laid up. Provision must also be made for keeping the lubricating oil cool when running.

When all this is done the question arises, "Can the job be produced commercially?" The manufacturers will probably say it is impossible, though everything except the oil pump and the water by-pass is to be found in the power unit of the Ford car, which has a radiator in addition. The second question for consideration is, "Does a complete power unit, with gears continuously in mesh, so that reversing is a simple operation which can be rapidly performed, meet all the requirements?" The owner will reply in the negative. There are certain examinations that must be made periodically, and these must be easy to perform; working on a boat is not like working in a garage, much time is lost in going ashore with parts, and it is difficult to do any fitting work on the boat, while lifting heavy parts is far more awkward in a boat than it is ashore.

Taking these operations of maintenance in order, the first, in point of magnitude, is decarbonising, for which the owner prefers an engine having detachable cylinder heads. Accompanying this operation advantage is generally taken of the dismantling to grind in the valves; this is simpler and easier to perform with overhead valves, which have the additional advantage of being adjusted more readily. The old oil requires to be cleaned out of the crank-case, the oil filter cleaned and the pump examined; both of these details are often made very inaccessible, but they should be so designed as to be removable from above. The water jackets need to be washed out and the water pump and pipes cleared; provision can be made by means of plugs suitably placed and of ample size for the first task, and ease of access when in the boat must be ensured for the others. Electric connections, magneto and plugs have next to be considered; the horizontal magneto is very inconvenient on a boat, and a vertical pattern bringing the contact breaker nearer to the top of the engine and making the vital parts easy of access and examination from above is really necessary. Then comes the petrol supply with its filter and the carburettor; all carburettor parts, nipples or nuts for connections should be of standard hexagon nut sizes so that set spanners can be used. Lastly, it is very important that the whole of the engine and gear-box casing must be watertight.

Can the marine motor engine designer incorporate in his designs all that has been considered essential? Probably he can, because some of the engines recently exhibited comprise nearly all the features that have been specified as necessary. Can the marine motor manufacturer make and supply such engines at a commercial price? This is a more doubtful question, because in some designs there is no alternative but to scrap the existing models. At all events, it is certainly desirable that the designer and the manufacturer should get into touch more closely with the actual conditions under which their engines are run, laid up, maintained and repaired.

THE DETERIORATION OF STRUCTURES IN SEA WATER.

THE Department of Scientific and Industrial Research has just published the Third Interim Report of the Committee of the Institution of Civil Engineers that has been engaged since 1916 in investigating the deterioration of structures in sea water and allied subjects.* The report begins with a feeling reference to the death, in 1922, of Sir William Matthews, the committee's first chairman. The Second Interim Report, issued in 1922, announced his retirement through ill-health, and bore testimony to his enthusiasm and energy in the Research, and his labours will doubtless continue through many years to exercise a most beneficial influence on the investigations of the Committee.

The present report records a considerable amount of work done in pursuance of the general scheme of investigation, together with a few results to be deduced from them, while an abstract is also given of the 1921 report of the San Francisco Bay Marine Piling Committee instituted by the American Wood Preservers' Association, which is proceeding with a vigour which has been enhanced by reason of a recent serious outbreak of activity of wood-boring molluscs in the bay.

The specimens—bars 24 in. by 3 in. by ½ in.—of steels and wrought and cast-iron prepared under the direction of Sir Robert Hadfield* in order to test the action on them of sea water and the atmosphere during prolonged exposure, have reached their destinations and are placed in position. Each set of these specimens includes a medium carbon steel with low sulphur and phosphorus with a duplicate sample ground all over; a mild steel with low manganese and high sulphur and phosphorus; a mild steel with 0·7 per cent. manganese and a duplicate ground all over; a steel with 0·4 per cent. carbon; mild steels with ⅛ per cent. and 2 per cent. copper; a steel (Galahad "non-rusting") with 13½ per cent. chromium; steels with 3½ per cent. and 36 per cent. nickel; Armco, Low Moor and Swedish wrought iron, and Lilleshall hot and cold blast cast-iron. Except as stated every bar was left with its original skin on. All bars were drilled top and bottom with one or more holes, the position of which corresponded to a code giving the class of material according to the above list and the individual specimen numbers out of the 1,330 bars that had been prepared and weighed.

At each port of observation sets of these bars, secured in frames by concrete extending to beyond the holes (the exposed surfaces being carefully measured) were totally submerged below the lowest low-water level, others were fixed midway between high and low water levels, so as to give the effect of alternate wet and dry conditions, and others were placed well above the highest high-water level, so as to give the effect of aerial conditions in the neighbourhood of the water. In each case three series of such sets have been exposed, these being intended for removal at the end of five, ten and fifteen years respectively, with periodical observations in the meantime. A fourth series was prepared for fresh-water experiments, and a fifth—how distinguished from the first is not stated—for exposure in sea water and removal after five years.

Further series of specimens were prepared for the purpose of indicating any electrolytic effect resulting from contact of dissimilar metals. Three of these pairs were arranged with their faces flat against each other. These pairs consisted respectively of medium steel and 36 per cent. nickel steel, of mild steel with high sulphur and hot blast cast-iron, and of mild steel containing 0·7 per cent. of manganese ground all over and Low Moor iron.

Another bar of the high-sulphur mild steel was provided with four ⅞-in. rivets, as was also one of the chromium steel, while four ⅞-in. bolts secured by nuts were put through each of four separate bars of the 0·4 per cent. carbon and 36 per cent. nickel steels, and the hot and cold blast cast-irons. Further, a frame was built up of two bars of 0·7 per cent. manganese mild steel, ground all over, and two bars Swedish iron, secured at the four corners by ⅞-in. rivets, while a similar frame was made of chromium steel and Low Moor iron. Bars of medium steel with low sulphur, 36 per cent. nickel steel, and Armco iron were bent to a right angle and secured so that the angle was fully exposed to corrosion. Only one set of these composite or bent specimens was sent to each port; they are to be removed at the end of five years.

These sets of specimens have been exposed in Plymouth, Auckland (N.Z.), Colombo and Halifax (N.S.), these ports being selected to represent temperate, warm and cold climates respectively. The Plymouth and Colombo collections were exposed in April, 1922, and no results obtained with them are yet reported. The Auckland collection was exposed in September, 1921, and in a report by Mr. W. H. Hamer, the engineer to the Harbour Board, particulars are given of the appearance of the aerial and the wet and dry specimens after six months' exposure. With the exception of the nickel steel all the aerial individual bars showed considerable corrosion, amounting in some cases to flaking, while the composite or bent series were on the whole in a better condition, the bolts being less affected than the bars, but with two exceptions all bars in the riveted frames were corroded except where sheltered. Most of the wet and dry individual bars were more or less heavily rusted and overgrown with small white barnacles, some pimples of red rust being also occasionally seen. All the composite and bent bars except one were much rusted and corroded, and considerable corrosion was found in the frames, "with the exception of well-preserved bolts," of which, however, no mention is made in the committee's list of specimens. A detailed statement is stated to be given in Mr. Hamer's report of the precise condition of each specimen.

The Halifax collection was exposed in September, 1921, and from the summary given of the report by Mr. C. E. W. Dodwell, the harbour engineer, it appears that the aerial and wet and dry specimens were observed after three months, and the whole collection after just under five months. At the earlier examination all the aerial individual bars had stood very well except those of wrought iron (much corroded on the surface, but showing no perceptible pitting), and so had the aerial composite bent specimens, but the riveted frames and perhaps (the summary is not clear on the point) the composite mild steel with 0·7 per cent. manganese and Low Moor iron showed signs of surface corrosion. All the wet and dry specimens were more or less corroded on the surface, though without perceptible pitting, the wrought irons being the most affected among the individual bars and the cast-irons the least, while in the composite specimens the pair made of mild steel with high sulphur and hot blast cast-iron were the least affected. Neither the aerial nor the wet and dry specimens had changed perceptibly at the later examination, except that the Galahad bar (it is not said from which condition of exposure) showed a little very slight pitting. At the later examination the submerged Galahad steel, ground mild steel with 0·7 per cent. manganese, and Low Moor and Swedish charcoal irons were much corroded on the surface with a "soft blister-like or frothy looking corrosion." The other individual bars were all slightly corroded on the surface, but with no perceptible pitting beneath. In the composite and bent series the pair made of ground mild steel with 0·7 per cent. manganese and Low Moor iron and all bars in the riveted frames were much corroded on the surface, though with no perceptible pitting beneath; all the other bars were slightly corroded on the surface; all rivet heads were also much corroded on the surface, but the bolts and nuts were hardly affected.

No analyses of the sea water are given. The specimens were protected during transit by petroleum jelly, which was directed to be thoroughly wiped off before exposure. An examination by Dr. J. N. Friend of mild steel plates that had been coated with the jelly and kept for thirteen months showed slight rustiness, with a loss of weight of the order of 0·015 per cent. to 0·03 per cent., an amount that would be negligible in the thick bars used for the research.

Dr. Friend has also made two incidental reports on associated subjects. In the one he considers replies received to 10 questions that had been submitted to 50 shipowners, railway companies and large users of paint and other protective coatings employed to preserve steel and iron structures exposed to sea action, intended to elicit their experience, practice and difficulties. The results show much diversity of practice, which seems to call for further research, and the committee are considering the possibility of making experiments to test the relative merits of some protective preparations and the methods of their application.

In his other report Dr. Friend describes some interesting experiments on the susceptibility of strained iron and iron alloys to corrosion in neutral media. From seven tensile test bars of materials that were to be included in the exposure tests, and that had been heat-treated and broken under test, sections were cut at three points, one from immediately under the grips, where the material could be regarded as free from appreciable strain, and the other two through points near the fracture at which the

* Deterioration of Structures of Timber, Metal, and Concrete Exposed to the Action of Sea Water: Third (Interim) Report of the Committee of the Institution of Civil Engineers. Edited by P. M. Gosthwaite, Secretary of Committee, and Gilbert R. Redgrave. H.M. Stationery Office. 3s. 0d. (post free, 3s. 2d.).

* See the paper by Sir Robert A. Hadfield, read before the Institution of Civil Engineers, of which an abstract was published in ENGINEERING of April 7, 1922, p. 419.

elongations had been determined previously, and had shown respectively that the metal was in its most strained condition and in about half that amount of strain. The sections weighed about 20 grammes each, and each could be assumed to be strained uniformly throughout its small bulk.

Each of these specimens was carefully machined and polished. It was found that without exception the specific gravity of each material had fallen as the strain increased, thus indicating that the type of cold-working that is applied in a tensile testing machine reduces the specific gravity of the metal. Other specimens were kept for a year on blocks of paraffin wax in a tank, which was alternately filled with tap water and emptied by syphonic action, so as to give alternately wet and dry conditions. The materials thus tested were the Low Moor iron (0·015 per cent. carbon and a trace of manganese), Armco iron (0·035 per cent. carbon and 0·065 per cent. mangansee), mild steel (0·24 per cent. carbon and 0·68 per cent. manganese), medium carbon steel (0·345 per cent. carbon and 0·71 per cent. manganese), carbon steel 0·40 per cent. carbon and 0·85 per cent. manganese), nickel steel (0·12 per cent. carbon and 36·6 per cent. nickel), and Galahad steel (0·36 per cent. carbon and 13·57 per cent. chromium).

As a result the irons and non-alloy steels not only showed no appreciable difference in corrodibility between strained and unstrained specimens—in three out of the five materials the strained specimens showed in fact a shade less corrosion measured by loss of weight than the unstrained—but the actual difference in corrosion between the several unstrained materials was insignificant—5 per cent. or less. Both strained specimens of nickel steel, on the other hand, showed about 4½ times the corrosion of the unstrained specimen. The strained chromium steel specimens also showed respectively a third more and double corrosion as compared with the unstrained, though Dr. Friend remarks very fairly that the differences—respectively one-tenth and three-tenths of a milligramme—almost lie within the range of experimental error. Dr. Friend points out that the results given by the non-alloy metals are quite consistent with increased corrodibility of strained material in practice, seeing that under the conditions of experiment each specimen was probably strained uniformly throughout its bulk and insulated from any metal in another state of strain, neither of which conditions would be present in practice. Perhaps if the experiments are repeated controls will be arranged in which contact will be made between strained and unstrained sections of the same specimen. It seems possible, too, that the assumption of uniform strain throughout the entire section may be less warrantable in the presumably far stronger and tougher alloy steels than it is in the irons and straight steels.

In 1917 a number of slabs of reinforced concrete were exposed in the Brisbane River at a point where the water was practically as salt as sea-water, the blocks varying in the extent to which the reinforcement was covered, and to some extent in the composition of the concrete. From a note by Mr. E. A. Cullen, engineer to the Harbours and Rivers Department at Brisbane, it appears that although less additional rusting than had been expected has occurred since the last examination eighteen months ago, nothing less than 2 in. covering is sufficient, so far as these observations go, to give complete protection. In the blocks with thinner coverings little difference has been found in the deterioration between 2 sand-1 cement concrete and 4 sand-3 cement. In a reinforced concrete wharf on the Brisbane River completed by Mr. Cullen in March, 1917, the piles and girders have 2-in. cover over the reinforcement, and the whole structure was well tarred with hot distilled tar on all surfaces except the deck, the tar being carried down the piles to about the level of mean neap high water, and the tarring being repeated a year later. Below mean sea level the piles are encrusted with small barnacles, but on recent examination, five and a-half years after completion, no corrosion had occurred.

The investigations of timber continue to reveal wide differences in the experience of different observers. The most comprehensive account of the practical occurrence of organisms attacking timber is given in a report on boring organisms in various waters by Mr. J. E. Cunningham, the inventor of the carbo-teredo process for protecting timber against such organisms. This process consists in coating the timber with vaseline, which is then strongly heated and ignited with a hand lamp, so that the timber is more or less evenly and deeply charred. Knots in the timber are then impregnated again and recharred; so are cut ends, the char being consolidated by hammering up. On the basis of timbers so treated and kept both in quiet waters and in the open sea for three to seven years Mr. Cunningham claims that both pine and hardwood so treated are proof for at least that period against sea worms, the animalculæ on which they feed, and other organisms that attack timber, while even turpentine wood, if untreated, is badly attacked when placed side by side with intact treated timber. On the other hand, Mr. W. H. Hamer found turpentine wood stand sound for four years, whether treated or not, under conditions in which a number of other woods treated by the carboteredo process were attacked or even destroyed.

To what extent the failures of the process reported by Mr. Hamer have happened because it does not always protect or (as in general terms Mr. Cunningham explains such failures as he has himself known), because it has not been properly applied, is not clear on the published particulars. What, however, is clear from these reports and another by Mr. A. C. W. Fosbery, the chief engineer of the Bombay Port Trust, and the experience of the San Francisco Bay Marine Piling Committee, is that few, if any, untreated timbers can offer prolonged resistance to the attack of organisms, and that no completely adequate means of protection has as yet been demonstrated.

Accordingly the most hopeful of the Committee's labours may be the various investigations into the fundamental facts of the life history of marine timber-boring organisms, the circumstances and methods of their lodgment and attack, and their reaction to various protective substances or processes. In one series of experiments, Dr. George Barger supplied Professor S. M. Dixon with a number of "poisons" insoluble in water, but soluble in alcohol, of which 1 per cent. and 0·1 per cent. solutions were impregnated into blocks of wood, and exposed for a year off Lowestoft pier. The impregnation appears mostly to have penetrated only ⅛ in. to ¼ in., and all that can be said of the results is that they show clear differences between the poisons, which might be more apparent—or less—if the impregnation had been less superficial. For the period in question impregnation with creosote, which penetrated throughout the substance of the block, was completely effective, as were two of the poisons.

Under Dr. Barger's direction, also, Mr. C. B. Harington carried out a number of experiments in Plymouth Sound and in a laboratory, which, among other results of scientific importance, showed that in the presence of appropriate food the larvæ of the organisms in question could swim about for a fortnight, and thus might infect timber at a considerable distance, and that they are definitely attracted by certain chemical substances. Professor Dixon describes the methods he used for creosoting and applying "poisons" to timbers, during which he noticed considerable differences between the extent to which various timbers absorbed the impregnating solutions. An interesting detail of the method is that in all cases the blocks were furnished with a veneer of untreated wood, which enabled organisms to get a start and attack poisoned woods which they failed to attack in the absence of the "appetiser" veneer. Professor Dixon has also carried out a large number of mechanical tests on specimens of timber, from the Colonies and elsewhere, both untreated and after creosoting, the results of which will be published later.

In previous reports reference was made to the receipt from the Committee's Corresponding Members and other sources of specimens and photographs of materials and organisms illustrating the sources and stages of deterioration. These have been collected in a museum installed at the Institution of Civil Engineers, to which valuable additions have been made during the year under notice. A revised catalogue has been prepared, and with the history of each specimen catalogued in context with the exhibit the museum now contains a collection that already is unique, and is certain to increase in extent and value every year.

From a circular letter issued by the Council of the Institution of Civil Engineers to certain authorities whom the research must interest, it appears that the time has arrived for considering seriously the financial resources available for carrying on the work. The Institution has itself provided free of all cost the necessary accommodation on its premises for the museum and for the committee's clerical staff, but the state of the Institution funds does not allow it to promise a definite annual money grant towards the cost of the research. The Committee has also had the benefit free of charge of the services of certain harbour authorities, engineers and others. But with these exceptions the entire cost of the research up to now has been borne by the Scientific and Industrial Research Department, who in 1916, agreed to provide 8,000*l.*—over a term of years—and by March 31 of this year had actually provided 8,490*l.*

The department is prepared to make further grants, but in accordance with the practice that it has recently established requires that half the cost of the research shall be borne out of other funds. It is estimated that in the first instance the research will cost about 1,250*l.* a year for five years, and this involves assuring outside the department's grant about 600*l.* or 700*l.* a year for that period. The Council of the Institution is now appealing for guarantees for the current year, and succeeding four years, which would be called on *pro rata* as the requirements of each year were ascertained.

It is to be hoped that the appeal may be completely successful and that substantial support may be received from the numerous harbour authorities who will be benefited by the results of the research. When the wide scope of the investigation is considered, and the great diversity of methods that have to be used, the amounts already spent and now required seem remarkably low. They certainly are trivial in relation to the enormous material interests at stake, and the nature of the phenomena to be observed. Maturing as they do mostly after a period of years as against the hours or minutes in which the results of many other researches develop, it is certain that any discontinuity in the carrying out of the present investigations before they had attained their object would be a very grave misfortune.

DOCK LABOUR AND PORT GOVERNMENT.

There is a natural tendency at the moment to consider unemployment as a heritage of the war. The present abnormal condition is certainly in large measure such a heritage, but unemployment was with us before the war and will remain when the tumult and shouting have passed into history. Apart from exceptional periods of great unemployment accompanying periods of bad trade which have come and gone in the past, sometimes for no very apparent reason, unemployment in some measure is a normal phenomenon of industry. In certain trades it is seasonal and may be inherent in the conditions of a trade. In others, however, it is chronic, and can only be explained either as due to faulty organisation or to the total body of labour connected with the trade being larger than it can properly carry.

At a time like the present a surplus of labour may well be attracted into any industry which offers a prospect of work, but in normal times the existence of a labour force in excess of the work available suggests that a trade offers special attractions either by unduly high wages or unduly easy conditions. Dock labour appears an excellent example of a trade the unemployment in which is unduly increased in this way, and some useful comments on the subject were given in Sir Joseph Broodbank's presidential address to the Institute of Transport last Monday. He suggested that the organisation of labour in some ports was little better than the organisation of hop-picking, and pointed out that the two principal causes of the unsatisfactory position were the high wages paid to the men when at work and the lack of organisation of the industry in which they were employed. "If

economic conditions were allowed free play . . . gradually the extra men attracted by war pay would be eliminated and a fair wage secured to the smaller number of men who would get more regular work." There is no doubt at all but that this contention is absolutely correct, and powerful labour organisations do their cause and their members no ultimate good by forcing wages up to a standard which cannot be maintained. Something of the same kind happened in the coal-mining industry, but it ultimately collapsed under the pressure of economic events.

Sir Joseph's second point—that of organisation—is, however, one that has much bearing on the question of unemployment and casual labour at the docks. He pointed out that in the Port of London there are literally hundreds of masters on the dock quays. These vary from small contractors employing, say, 20 men, up to large concerns employing, perhaps, 1,000. It is inherent in the nature of dock work that each of these employers requires a margin of labour to enable him to cope with busy periods, and the ultimate result of the whole system is that a very large body of casual labour has become attached to the port, and is indeed a necessary feature of its operations under present conditions. If, however, one body could be made the authority for employing and organising labour throughout the port, the load could be better distributed and the total amount of casual labour could be enormously reduced. Quite apart from the obvious difficulty of organising such a common employer, and the natural opposition which present contractors would offer to a scheme which aimed at eliminating them, it is clear that opposition might be expected from some branches of labour. Many of the men would object to the interchange of work which would be a necessary feature of the scheme, while the type of man who objects to working every day of the week would certainly offer no support. These difficulties are very grave and real ones, and there is certainly no likelihood of the scheme being realised in the near future. It is well, however, to have attention called to it, and to have it pointed out that a very large floating mass of casual labour is not a necessary feature of the London docks.

The organisation of port labour on a permanent basis would, it has been suggested, create a close corporation of employees, which would dominate the port for its own ends; but, as Sir Joseph Broodbank pointed out, the labour of railway companies, not to mention most other big industries, is organised on such a permanent basis, and railway employees have not given their employers anything like so much trouble during recent years as have dockers. In any case, the argument that dock labour must be kept casual so that dockers' unions cannot become powerful bodies is a quite inadmissible argument.

It is probable that the casual labour question is a particularly difficult one in the port of London owing to the scattered nature of the dock estate. The London docks, wharves and warehouses are spread over nearly 30 miles of river, and in this respect compare very unfavourably with the arrangements in concentrated ports like Liverpool, Antwerp, Hamburg, &c. The scattered arrangements in London are a legacy from the competition between the statutory dock companies which was initiated in 1823, and must lead to a greater body of casual labour than would be necessary if the docks were all contiguous and easily reached one from the other. Conditions must be accepted as they are, but a general policy of concentration might be evolved and slowly worked up to. Sir Joseph Broodbank points out that the construction of the King George V Dock alongside the Royal Albert Dock was a step towards such concentration. The latest scheme at Tilbury, however, runs counter to any such ideas, and Sir Joseph's comment is that "the departure of the Port of London Authority from the policy first adopted is not easy to follow."

SHIPBREAKING AT QUEENBOROUGH.

IN the early months of the present year there was inaugurated at Queenborough, on the Island of Sheppey, an industrial enterprise of considerable magnitude. Messrs. Cox and Danks, Limited, of 186, Regent-street, London, who are well known as iron and steel merchants, decided to combine the business of shipbreaking with their other activities, and to that end acquired a lease of the pier, offices and warehouses formerly used in connection with the Queenborough-Flushing shipping service. The site is well adapted for the purpose in view, and affords comfortable facilities for the demolition of several large vessels at once.

The first two vessels to be brought in for demolition were the dreadnoughts Orion and Erin, sentenced to destruction under the Washington Agreement. The Orion, commissioned in 1912, was of 22,500 tons displacement and carried as main armament ten 13·5-in. guns. She was driven by Parsons' turbines aggregating 29,000 h.p., arranged on four shafts, and had a speed of 21 knots. Her length was 545 ft., and her beam 88½ ft., her draught 27½ ft. and her cost close on 2,000,000*l*. The Erin was built by Messrs. Vickers for the Turkish Government under the name of the Reshadieh. She had not been delivered at the time war broke out, and was taken

FIG. 9. CUTTING DECK WITH ACETYLENE TORCH.

over by the British Government and put into commission in August, 1914. The Erin was comparable with the Orion in size, having a displacement of 23,000 tons and a length and beam of 525 ft. and 91½ ft. respectively. In speed and main armament the two vessels were identical, and both had a 12-in. armour belt. Both of these vessels were at the battle of Jutland.

In addition to the warships mentioned, there is also lying at the wharf the floating dock built during the war by the Germans for dry-docking and testing submarines. The dock, which was fully illustrated and described in our issue of February 25, 1921, is very similar to an ordinary floating dock except that midway between the walls is a cylindrical chamber 380 ft. long by 39 ft. 5 in. diameter. This is fitted with a door at one end, and its purpose is to enable a submarine to be tested under external water pressure. The submarine is floated inside the cylinder, the door is closed, and a water pressure maintained in the chamber by means of centrifugal pumps. Pressures up to 114 lb. per square inch, corresponding to an immersion depth of over 260 ft., can be applied to the enclosed submarine. On each side of this testing chamber is a berth upon which a submarine can be dry docked.

In view of the interesting features of this floating dock, and of the work of demolition in progress on the battleships, Messrs. Cox and Danks, Limited, kindly gave the members of the Institution of Mechanical Engineers an opportunity of inspecting their Queenborough establishment last Saturday afternoon. The firm conveyed its guests, numbering nearly 300, from London to Queenborough, in a special train chartered for the occasion. The visitors were very interested in watching the cutting up of the guns, turrets and other large masses of metal by means of oxy-acetylene apparatus of Messrs. Cox and Danks' own design. The burner was carried on a long slide attached to the work to be cut, and was traversed along as the cut proceeded by a small electric motor. The heaviest cutting appeared to be in connection with the breeches of the big 13·5-in. guns. The flame in this case cut through 21 in. of solid metal, including the wire winding, leaving a comparatively smooth-sided cut about ½ in. wide. The 10-in. armour plating of the turrets was cut into rectangular slabs of a weight suitable for transport, the cut surfaces being extraordinarily smooth and regular considering the method employed.

The illustrations we publish on our two-page Plate and the present page, which are reproduced from photographs taken by the Sport and General Press Agency, Ltd., indicate very well the class of work which Messrs. Cox and Danks, Limited, are carrying out at Queenborough. The submarine dock brought there for demolition is illustrated in Figs. 1 to 3, on Plate XXIII. The magnitude of the structure is shown by the first pair of photographs, while the bracing of the pressure chamber and the side berth for dry-docking are clear in Fig. 3. The next illustration, Fig. 4, shows the 13·5-in. guns in the after turret of the Orion before the work of destroying them had been started. Demolition is commenced by cutting short lengths from the guns commencing from the muzzle ends. The appearance of the guns of the forward turret of the Erin after the muzzles have been cut away in the manner stated are shown in Fig. 5, in which the radial grooving left by the action of the oxy-acetylene flame can be clearly seen. The next illustration, Fig. 6, is of unusual interest. It shows the breech portion of one of the big guns of the Erin, with half the jacket being lifted away after horizontal cuts right through to the bore had been made on each side by the oxy-acetylene flame. The wire-winding is well shown in the illustration.

A further example of some very heavy cutting is seen in Fig. 7, where a piece of 15-in. armour plate which has been cut through is lying in the foreground, the cut face being prominently shown. The last photograph on the Plate, namely, Fig. 8, is a view taken from the Erin, showing the Orion in the background, and well illustrating the work of destruction. The cutting-up of the guns and turrets is perhaps the most striking of the operations, but the demolition of the structure of the vessel itself, though not so spectacular, constitutes the greater proportion of the work. This is also carried out by oxy-acetylene, the steel plating and girders being cut into pieces convenient for removal without regard to riveted seams. Fig. 9, annexed, shows a man engaged on the demolition of some of the structural work, which is very rapidly carried out as compared with the heavy cutting required in the case of guns and armour.

NOTES.

BRITISH COMMERCIAL GAS ASSOCIATION.

THE twelfth annual conference of the association was held at Birmingham on Monday, October 1, and the two following days. Alderman J. H. Lloyd, the president, opened the proceedings with an address, in which he dealt with the history of the Birmingham gas undertaking, of which he is now the chairman, the organisation and service to the nation of the industry and the progress of the association. The papers read were divided into two groups. In the first, that of "Gas in Catering," contributions were submitted by Messrs. R. G. Marsh, H. Clark, W. Wilson and W. B. McLusky. The other section comprised papers on "Gas in Industry." Mr. A. W. Smith discussed "The Practical Advantages of Gas Service to the Manufacturers," and described the demonstration rooms and laboratories of the Birmingham Corporation in which there are examples of the different types of furnaces with which trials can be conducted for

manufacturers, to determine the most suitable type of plant and the conditions of its operation for any particular service. Examples of industries to which gas has been successfully applied were cited, and the methods of their utilisation of gas described. Dr. C. M. Walter, of the Industrial Research Laboratories at Birmingham, discussed "Heat Treatment by Town's Gas in Midland Industries," and described many successful adaptations of gas furnaces to meet the specific needs of many different trades. "The Use of Gas in the Boot and Shoe Industry" provided Mr. G. S. Eunson with a theme on which he gave information of the experiences of users in Northampton.

Science and Experiment.

That modern science and scientific progress are based on experiment it is hardly necessary to say, but it is at times useful to remember that mere experiment without able deduction from results can lead us but a little way. This truism is at times in danger of being forgotten. The mere fact that more and more laboratories are built and equipped in which more and more experiments can be carried out is at times apparently considered to be all that is necessary to keep a country in the forefront of advance, and Sir George Beilby did technical education a service when he dwelt on the greater importance of the interpretation of experiment than the experiments themselves. When opening the new Metallurgical Laboratories at the University of Manchester last month, Sir George referred to the constructive work of the pioneers in metallurgy and pointed out as an example that Henry Cort, in his epoch-making work on malleable iron 140 years ago, although he probably had little systematic knowledge of science, yet by his observing power and constructive thought had laid the foundations of a great industry. Cort's constructive thought was the cause of his great contributions to progress, and the necessity for such constructive thought was as great as ever. Scientific knowledge and scientific method were but tools, and good work could only come from metallurgical laboratories if good men were available to interpret the work that was done. This insistence on the necessity for constructive thought applied to experimental results should be of value to the students of Manchester, and should keep them clear from the fallacy of supposing that the experiments themselves serve any end. One may trust that the new laboratories under Professor Thompson's valuable direction may produce many workers who will not only add to the mass of recorded results, but will be capable of synthetically building up from them to valuable ends.

THE LATE ALDERMAN CHARLES F. DIXON.

Darlington has suffered a keen loss both in the field of industrial activity and municipal life by the death at the age of 64 years of Charles Frederick Dixon, which occurred at his residence, Raventhorpe, Darlington, on Tuesday, September 25. He was chairman and managing director of the Cleveland Bridge and Engineering Company, Limited, and an alderman of the town.

The second son of the late Henry I. Dixon, of Stumperlow Hall, Sheffield, he was educated at Marlborough, and afterwards obtained business training in Sheffield. In 1882 he was appointed secretary to the Cleveland Bridge Company, which he purchased three years later and ran as a private concern until 1893, when he formed the present limited liability company. From small beginnings the business was extended under his care, until it was brought to its present position in the field of construction. Many outstanding examples of the work of his firm are to be found at home and abroad, of which the bridge over the Zambesi in Central Africa may be cited as an example which showed skill and enterprise in its construction and erection. With the late Mr. Owen Pease, Alderman Dixon founded the Cleveland Car Company, and he rendered great service as chairman of the Gas Committee of his adopted town.

Faraday House Old Students' Association.—We understand that the fifteenth annual dinner of the Faraday House Old Students' Association will be held at the Hotel Cecil on Friday, October 19. Mr. H. W. Miller, M.I.E.E., will be in the chair. Members of the association may introduce guests, who need not necessarily be Faradians. Old students who are desirous of attending should make early application for tickets to the Secretary, Faraday House, Southampton-row, London, W.C. 1.

THE LATE MR. HAROLD COPPERTHWAITE.

Railway engineers and others of his many personal friends will learn with regret of the death of Mr. Harold Copperthwaite, who was, at one time, engineer to the southern division of the North Eastern Railway. He passed away, at his home, 2, The Crescent, Scarborough, at the age of 85 years, on Saturday, September 29, after a short illness.

He was the son of the late W. C. Copperthwaite, a director of the North Eastern Railway Company, and entered the service of the company in 1856, when he was 18 years of age. At that time the chief engineer was Mr. T. E. Harrison, who was coadjutor of Robert Stephenson in the design and building of the High Level Bridge at Newcastle-on-Tyne and other great undertakings. After some years Mr. Copperthwaite joined the staff of the North British Railway Company, and later became engineer to the Blyth and Tyne Railway. In 1874, when the North Eastern Railway absorbed the smaller concern, he returned to the service of his old company, and in 1884, when Mr. Joseph Cabry was promoted to the central division, Mr. Copperthwaite succeeded him in the southern division and remained as chief of that section until his retirement in 1899. Under his care many important engineering works were undertaken by the company in the southern section, particularly in Leeds and Hull. He was elected Assoc.M.Inst.C.E. in 1875, and was raised to full membership in 1880.

LOCOMOTIVE COPPER STAYS.

To the Editor of Engineering.

Sir,—In your issue of September 28, Mr. H. N. Gresley criticises our suggested form of stay, his chief objection being that stays heads are burned off, that the new design would not obviate this and it is not therefore likely to prove satisfactory. We should be very pleased if Mr. Gresley or any other locomotive engineer would answer the following questions for us, as we believe that they have a distinct bearing on the solution of what is a source of trouble and expense, namely, stay replacement.

(1) What is the cause of the burning of the heads? Is it oxidation or corrosion or erosion?

(2) If it is oxidation, would not a perfect metal-to-metal contact between stay and plate reduce the effect by a more rapid dissipation of the heat into the water? Stays as used at present allow the ingress of scale which is a bad heat conductor, and we suggest this as a contributory cause of the burning-off.

(3) If it is corrosion through chemical action, then we would suggest that a modification of our design of stay having no head at all, but flush with the plate and expanded in the hole, would resist corrosion almost as long as the fire-box plate.

(4) If it is erosion through friction of the fuel particles, then perhaps the same flush design would resist this.

This principle is used for the boiler tubes which are expanded in the tube plate, why not use it also for the copper stays?

We do not think that our form of stay need be any weaker than a stay with a tell-tale hole drilled through it. Nor do we think that there would be any danger of the stay pulling out through the hole closing in even in a flush stay. The metal would be stressed during the expansion beyond its elastic limit, and with a perfect metal-to-metal contact we think our stay would hold longer than the ordinary stay even under the sideways stresses that are encountered through expansion of the fire-box plate, when the boiler is fired.

There must be a mistake in the drawing of the stay in Mr. Gresley's letter, as the apparent shoulders at the inner ends of the threads would prevent the stays being inserted.

Yours faithfully,
Alfred Herbert, Limited.

Coventry, England, October 2, 1923.

[The defect referred to in the last paragraph of the above letter is due to an error on the part of the engraver. There are no such enlarged shoulders on Mr. Gresley's drawing.—Ed. E.]

THE STANDARD OF THE B.Sc. DEGREE.

To the Editor of Engineering.

Sir,—Those of your readers who hold degrees in engineering will read with regret that portion of your editorial of the 28th ult. deprecating the standard of the B.Sc. degree given by some universities, &c. In a journal which is regarded at home and abroad as the "*Times*" of the technical press, it is essential that such charges should be well grounded and definite, and I shall only be voicing the opinion of hundreds of your readers in asking that future attacks should be less general in character and more precise in their condemnation. Sweeping statements are made from time to time in Engineering, written evidently by non-graduates, endeavouring to belittle holders of degrees generally, and resembling, in a manner, the attacks made by a well-known daily on the teaching profession. The standing of Engineering and its staff is such that these remarks unhappily are viewed less amusingly than similar statements in the non-technical press: an influential engineer recently said to the writer, "a graduate nowadays applying for any other than a teaching post will do well to keep his degree in the background, thanks to Engineering. This would be an amazing state of affairs if it were wholly true, but there is enough of the truth in it for graduates to ask that insinuations be dropped and only charges made that can be definitely challenged or accepted.

Who shall say that the present B.Sc. standard is a low one? A careful comparison of the course syllabuses and examination papers of the principal universities of Britain shows that the standard is far from low, and in engineering subjects certainly higher than that of papers set, say, fifteen years ago. Are the examination Boards accepting a lower marking standard for a pass? They only can say as to this. It is probable that the standard for two years or so following the armistice was lower than the average; it ought to have been! So the opinions given in Engineering are presumably based mainly on indifferent contributions received from certain graduates and badly-written recent text-book publications. The desire of a few budding authors to rush into print with undigested matter is no reason for regarding them as a fair sample of their class; this point needs no labouring.

The degree course of study makes the average man acutely aware of his limitations, and he soon realises that he is merely spooning from a vast reservoir of accumulated knowledge. The course simply prepares and trains the graduate *to carry on* his studies with little further guidance, and the degree represents a certain standard of education, that is all. Graduates merely expect the recognition of this standard; to blame them because their ranks do not contain a large proportion of Kelvins and Osborne Reynolds is to criticise unfairly.

I am, Sir, yours truly,
"Graduate."

INDUSTRIAL FATIGUE RESEARCH.

To the Editor of Engineering.

Sir,—My attention, on my return from holiday, has been called to the leading article (entitled "Factories and Workshops") on the Chief Inspector's Report, in your issue of August 10, more particularly to the closing paragraph.

Fair and intelligent criticism is both useful and salutary, but your closing paragraph is neither. You have completely misread the chapter in question. The work was done in my laboratory and under my direction. The workers were not concerned at the time with either maximum or excessive loads. As the title indicates, the problem was to discover which method of carriage required the least expenditure of energy. Obviously this did not require persons or subjects experienced in carriage of loads—indeed, the fact that they were not habituated to any one method of load carrying was a distinct advantage as the comparison was better.

I myself come of engineering stock and I admit it may be from the "practical" man's point of view a matter of opinion whether such investigations are of immediate value, but I did expect that a reviewer in such a sound journal as yours would have taken the trouble to have read at least the title of the communication under review.

I am, yours faithfully,
E. P. Cathcart.

University of Glasgow, October 1, 1923.

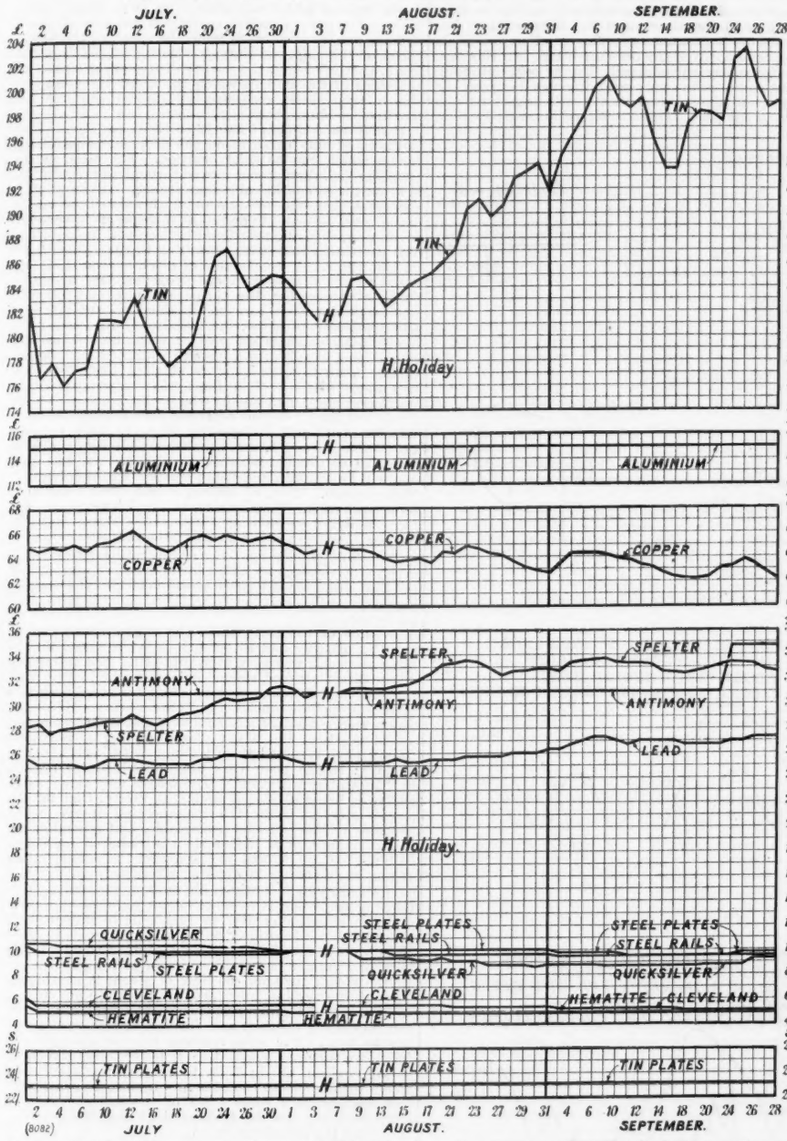
[The only paragraph to which Professor Cathcart can fairly take exception is that in which it is correctly stated that "it is difficult to see how the elaborate records taken throw any light upon the question as to what are, and what are not, excessive loads." We regret that we devoted more time trying to discover some useful information in the text of the report than to studying its title, but to meet Professor Cathcart's complaint the above sentence may be modified to run "it is difficult to see how the elaborate records taken can lead to any material improvement in existing methods of handling goods in factories." Mr. F. W. Taylor, who years ago conducted an inquiry of this kind on scientific lines, recognised that both the material and the man were involved in the problem, and he arrived at really valuable results.—Ed. E.]

Civil Engineering and Town Planning.—Three series of lectures, arranged under the Bournville Village Trust Lecture Scheme, will be held at the University of Birmingham during the coming session. The inaugural lecture on "The City, its Past and its Future Form," will be delivered by Dr. Raymond Unwin, on October 9. The general historical and technical lectures will be the work of Mr. William Haywood, while specialised questions outside the scope of architecture will be treated by some of the civic officials of Birmingham. Mr. H. H. Humphries, the City Engineer, will deliver three lectures on the engineering questions involved, Dr. John Robertson, the Medical Officer of Health, will discuss the health aspects in two lectures, and Mr. F. C. Minshull, Chief Assistant Solicitor, will deal with the legal enactments. All particulars can be had from the Secretary of the University or from Professor F. C. Lea.

The Bradford Engineering Society.—The 25th session of this Society commences on Monday next, the 8th instant, when the President, Mr. Landor Baldwin, will deliver the inaugural address entitled "The Engineer's Place in Industry." A feature of the session's work will be the employment of the kinematograph to illustrate several of the lectures to be delivered. Among such lectures it may be mentioned those of Mr. C. Erith on the Riley Mechanical Stoker, of Mr. J. Shaw on the Electric Driving of Textile Mills, and of Mr. A. Spittle on the Production of Seamless Drawn Tubes and Sheets of Brass and Copper. The programme for the session also includes papers by Mr. F. K. Skevington on Reaction Turbines, by Mr. R. B. Davis on the Control of Combustion in Boiler Plants, and by Mr. D. Wilson on Coal Economy in Steam Raising, and several others. The membership of the Society now amounts to almost 350.

DIAGRAMS OF THREE MONTHS' FLUCTUATIONS IN PRICES OF METALS.

(Specially Compiled from Official Reports of London Metal Markets.)



NOTE.—In the diagrams the figures plotted for tin and copper are the official closing cash quotations of the London Metal Exchange for fine "foreign" and "standard" metal respectively. The prices shown for lead are for English metal, whilst those for spelter are for American metal. Middlesbrough prices are plotted for steel plates and rails, and also for hematite and Cleveland pig-iron. The prices given, in the case of steel plates are for ship, bridge and tank qualities, and those for steel rails are for heavy sections. The pig-iron prices are for East Coast hematite and Cleveland iron, both of No. 1 quality and for home consumption. The price of quicksilver is per bottle, the contents of which vary from 70 lbs. to 80 lbs. The price of tin-plates is per box of I.C. cokes f.o.b. at Welsh ports, but in other cases the prices are per ton. Each vertical line in the diagram represents a market-day, and the horizontal lines represent 1*l.* each, except in the case of the diagram relating to tin-plates, where they represent 1*s.* each.

LECTURES ON IONIC AND THERMIONIC VALVES.—Professor J. A. Fleming will give a course of six lectures on "Ionic and Thermionic Valves" at University College, on Wednesdays, at 5, beginning October 24. The course is open to a limited number. A syllabus of the lectures and particulars as to fees can be obtained on application to the Secretary, University College, London, W.C. 1.

DETECTION OF HYDROCYANIC ACID GAS.—Poisonous hydrocyanic acid gas is sometimes evolved in dangerous quantities from cyanides used in metallurgical and chemical operations. This gas is much used for fumigating buildings, ships, greenhouses, and such commodities as grain and cotton to destroy rats, mice and insect pests. Wherever cyanide fumes are evolved, thorough ventilation is necessary in order to render the surrounding air safe to breathe. Many persons have been killed by entering tanks and fumigated places too soon. In view of the need for a simple test for the detection of these gases, the United States Department of the Interior, at the Pittsburg experiment station of the Bureau of Mines, conducted a series of experiments which resulted in the development of colour test papers for detecting hydrocyanic acid gas vapour, in the air of tanks, apparatus, and in ships and buildings after fumigation. The shade of colour produced in tests, compared with a colour chart, gives an estimation of the concentration of the hydrocyanic acid gas over a range of 25 to 1,000 parts per 1,000,000 parts of air. The investigator's determinations in the laboratory were within 20 per cent. of those found by chemical analysis. It is recommmended that unprotected persons be not allowed to enter atmospheres containing hydrocyanic acid gas unless tests show concentrations not exceeding 100 parts per 1,000,000. The experimental work above referred to is described in Serial 2,504, by S. H. Katz and E. S. Longfellow, which may be obtained from the Department of the Interior, Bureau of Mines, Washington, D.C.

GUMMY DEPOSITS IN GAS METERS.

THE accumulation of gummy and resinous deposits in the gas meters of consumers, which has claimed serious attention over here, had in America by 1922 assumed such proportions as to induce the Bureau of Mines to open a fundamental investigation. These deposits, which were only reported from certain districts, were obviously connected with the unsaturated hydrocarbons resulting from the carburation of water gas and with the recently-adopted changes in the carburetting processes. It seemed therefore desirable to study the chemistry of gas condensates as well as to make a comparative survey of the practice in carburation plants, so far as the latter admits of control under working conditions.

It was found, according to a preliminary account on "Considerations of the Gummy Meter Problem in the Gas Industry" (serial No. 2,503 of the Reports of the United States Bureau of Mines), compiled by Ralph L. Brown, that the hydrocarbons forming a natural condensate in the distribution system of twenty water-gas plants contained from 20 to 50 per cent. of unsaturated hydrocarbons, largely of the gum-forming type. The main factors in the cracking of oil for gas-making are temperature, time, contact, atmosphere and pressure. The last two factors cannot be varied to any extent without changing the whole production. As regards temperature, Downing and Pohlman observed in 1916 that cracking above 1350 deg. F. (732 deg. C.) yields decidedly more gas of a slightly higher thermal value than working at lower temperatures. The survey mentioned showed that in eleven plants, which had not experienced any gumming trouble, the average carburettor temperature was 1,374 deg. F. (745 deg. C.), whilst in seven other plants, which did have trouble, the average temperature was 1,329 deg. F. (720 deg. C.). As the temperature is raised, the higher aromatic homologues (the so-called solvent naphtha constituents) of benzene are first decomposed; a high proportion of light oil of the solvent naphtha range in a carburetted water gas therefore suggests insufficient cracking. The cracking will likewise be insufficient when the period of the contact between the gas and the hot bricks of the carburettor is too short, that is, when the feed is too rapid, or the chequer bricks are spaced widely in order to reduce the back pressure. The increasing demand for carburetted water gas has increased the preferences for rapid feed and wide spacing. If cracking could mainly be effected by radiant heat—so far a very controversial point—direct contact and gas impact against the bricks would not be so essential. At present it is merely considered certain, however, that a brick becomes ineffective as contact surface in the measure of its becoming covered with the sooty carbon from decomposed oil gas. These relations can better be controlled with the aid of special acid scrubbers in which the unsaturated hydrocarbons and the partly-oxidised resinous products making up the washing loss are absorbed. The comparative figures given by Mr. Brown show that gas rich in toluene and benzene, but low in solvent naphtha, in washing loss and in residue distilling above 392 deg. F. (200 deg. C.), has not caused any gumming trouble, which had arisen in works when the stripping had been interrupted.

So far we have referred to the carburation. The cooling and condensation used to remove products that might condense in the pipes and meters, are equally important. There again the three factors mentioned, temperature, time and contact (with the cooling surfaces) come in. The survey indicates that the customary cooling of the gas to the average soil temperature and condensation (filtration through "tar cameras") are generally insufficient for this purpose. Benzene itself has too high a vapour pressure to be condensed at such a temperature, at any rate, at the probable benzene concentration of the gas. Condensation by liquefaction would overcome that difficulty. But it would not remove another serious source of trouble, the oxygen in the gas which oxidises the unsaturated and unstable constituents and turns them into resinous compounds. The proportion of oxygen is unfortunately increased by the purification needed for binding the sulphuretted hydrogen present in the gas. For this purification by means of iron oxide oxygen is required, but the theoretically-required amount of oxygen is only about 0·1 per cent., because the sulphur content of the gas is generally very small. Practically, however, a considerable excess of oxygen, nearly ten times the theoretical amount, has to be tolerated. Thus the problem of the gumming trouble reopens the question of the operation of the gas purification boxes.

POWER STATION FOR THE BRITISH EMPIRE EXHIBITION.—Work has now been started on the power station for the supply of electric energy to the British Empire Exhibition to be held at Wembley Park next year. The power station, which itself forms one of the exhibits in the Electrical and Allied Industries section of the Palace of Engineering will include three 1,500 kw. turbo-generator sets supplied with steam from water-tube boilers of two different makes. Each of the turbo-generators will be constructed by a different firm and the switchgear, condensing plant and auxiliary machinery generally will also be the work of several different firms. In addition a steam-driven dynamo and another driven by a horizontal internal-combustion engine each of 300 kw., will work on the stands of the makers in the main hall and will be connected up to panels on the power station switchboard. The whole of the electrical and allied engineering section of the exhibition has been organised by the British Electrical and Allied Manufacturers' Association.

TRIPLE FREQUENCY CURRENTS IN EARTH RETURN CIRCUITS.*

By Professor E. W. Marchant, D.Sc.

It is often found in large central stations that a current flows through the earth return lead to the neutral of the three-phase generators. It is well known that when the neutrals of a number of three-phase machines are connected together, large circulating currents will flow through the neutral connections of the machines. This phenomenon was described in some detail in a paper published by Mr. Catterson Smith, and the author in the *Electrician*.† It is now common practice to earth only one neutral in a generating station, but recently it has been observed that even when this is done there may still be a comparatively large current flowing through the neutral. One or two cases of this kind have come to the author's notice, and it may be of interest to describe the results of the observations and tests that have been made and to explain the phenomenon. In one case of a large system, a current of nearly 40 amperes was observed when the neutral of a machine, recently installed, was earthed. It had further been noticed that the amount of this current depended on the size of the cable network that was connected to the station, *i.e.*, when part of the cable network was disconnected, the current flowing was reduced. It was surmised, at first, that the current was due to leakage, but an examination of the wave shape of the neutral current showed that it was a capacity current flowing through the cable. Most of the high tension transmission systems that have been laid in this country, consist of three-core cables with the sheaths earthed. A diagrammatic representation of such a network is shown in Fig. 1.

The capacity currents flowing through the cables in the system due to the three-phase pressure applied, give no resultant current through the sheath, or whatever conductor is used as a neutral. But if there is a triple frequency component in the wave of pressure between phase and neutral, a triple frequency capacity current will flow, and the three currents in the three phases will produce a resultant triple frequency current through the earth return. This current will flow as shown in the diagram, Fig. 2. The three currents will flow to ground from the sheath of the cables, and if the neutral of the generators is earthed, the current will return through the earthing resistance. Examples of the currents observed through the earthing resistance are given in Figs. 3 and 4. It will be noticed in Figs. 4*a* and 4*b* that the current flowing has a complex wave shape, a relatively strong 15 times frequency component being present. This current is due to a tooth ripple in the wave shape of the alternator, and is not usually very large. The magnitude of the triple frequency current flowing is not greatly affected by the value of the earthing resistance, since the reactance due to the capacity of the cables is usually high. For a network of 60 miles of high-tension cable, the effective reactance will be about 50 ohms for triple frequency current at 150 cycles per second, and an earthing resistance of 4 ohms or 5 ohms will not reduce the earth current appreciably. For the higher frequency currents the capacity reactance is correspondingly decreased. For currents of 15 times the fundamental frequency the capacity reactance in the above system will be only 10 ohms, and is, therefore, more comparable with the values of earth resistance ordinarily used. The increase in the higher frequency harmonics produced by short-circuiting the earthing resistance is shown in Fig. 4*b*.

If the neutral of the alternator is not earthed there is clearly no return circuit for these currents, and the voltage of the neutral of the alternators will have a triple frequency pressure (measured to earth), equal to the triple frequency component of the pressure wave. In this case no triple frequency currents will flow to earth through the cable sheath, as the pressure difference between the cable cores and the earthed sheath will have no triple frequency component. This condition, however, does not usually exist in practice. These earth currents do not do much harm as far as the central station itself is concerned, and it is therefore, as a rule, not necessary to get rid of them, except in special cases. When it becomes necessary to reduce them, either the alternators must be rebuilt so as to give no triple frequency components of E.M.F. in their phase pressures, or else some device, similar to that described in the paper read by Mr. Turney and the author before this section, must be used. I am indebted to Messrs. Crompton Ramsay and Young for assistance in taking oscillograph records and for analysing the curves.

Fig. 1.

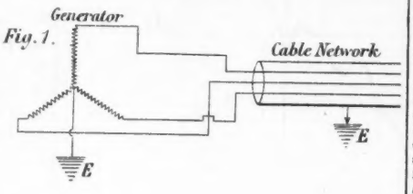


Fig. 2.

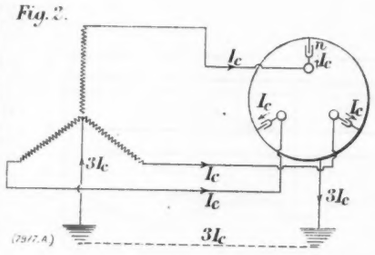


Fig. 3a. VOLTS BETWEEN PHASE AND NEUTRAL CURRENT THROUGH NEUTRAL OF 3000 K.W. ALTERNATOR (3 PH.) R.M.S. VOLTS 3800 R.M.S. CURRENT 5 AMPS.

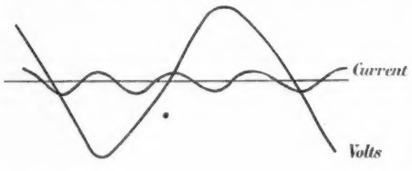


Fig. 3b. VOLTS BETWEEN PHASE AND NEUTRAL CURRENT THROUGH NEUTRAL OF 12,000 K.W. ALTERNATOR (3 PH.) R.M.S. VOLTS 3500 R.M.S. CURRENT 33 AMPS

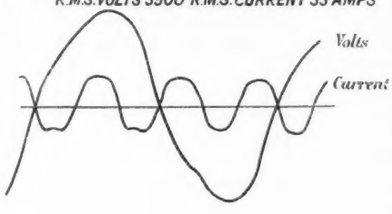
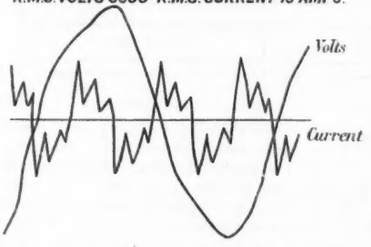


Fig. 4a. VOLTS BETWEEN PHASE AND NEUTRAL CURRENT THROUGH NEUTRAL OF 3500 K.W. ALTERNATOR (3 PH.) R.M.S. VOLTS 3500 R.M.S. CURRENT 9 AMPS.

Fig. 4b. VOLTS BETWEEN PHASE AND NEUTRAL CURRENT THROUGH NEUTRAL OF 3500 K.W. ALTERNATOR (3 PH.) WITH EARTH GRID SHORT CIRCUITED. R.M.S. VOLTS 3500 R.M.S. CURRENT 13 AMPS.



* Paper read before Section G of the British Association at Liverpool, September 19, 1923.

† *Electrician*, vol. lxiii, page 674, August, 1909.

ELECTRIC SHIP PROPULSION.*

By F. H. Clough, C.B.E., M.Inst.C.E., M.I.E.E.

Screws.—The design of a suitable screw propeller is rather a complicated matter, and, in fact, it is very largely determined by empirical rules based on the results obtained on other ships.

The area of the propeller must obviously have some relationship to the cross-sectional area of the ship, that is to say, large ships would have a large propeller; further, the water in which the propeller revolves is not rigid, and there is a limited amount of thrust which the water will stand without giving way. In other words, if the thrust on the propeller is too high, the water breaks, and "cavitation" as it is called, takes place. The point at which cavitation will occur is not a definite one, as it depends upon the speed of the screw, speed of the ship, and largely also on the form of the wake, that is to say, the nature of the water stream at the stern of the ship in which the screw revolves, and this in turn varies according to whether the ship has fine lines or blunt ones.

It may be said that some 12 to 13 lb. per square inch is the maximum pressure on the projected area of the blades which can be safely carried. The pitch of the propeller, *i.e.*, the distance moved through per revolution, is a matter of considerable importance. If the pitch is too great then the component of thrust will be small, and if small in order to permit an increase of the speed of revolution, then the rotational friction will be high, and also cavitation may take place due to centrifugal force on the water. A usual value of pitch is approximately equal to the diameter of the propeller. By assuming suitable values for the thrust pressure and pitch a first approximation can be obtained to the diameter and speed of the screw, but as already mentioned the final design depends on other factors, and is usually settled empirically from results obtained on similar ships. A single screw is more efficient than two, and two more efficient than four. For a comparatively low power ship, viz., one in which the horse-power per ton is less than 0·5, and equipped with a single screw, a suitable speed will be between 75 r.p.m. and perhaps 125 r.p.m. If two screws are fitted, obviously the total area will be divided between the two screws, and each one will be smaller, and being smaller, will revolve at a higher speed. This, of course, is extended when four screws are used. Usually also, two and four screw ships have a higher speed than single screw ships, and this further increases the sea speed of the propeller.

Propelling Machinery.—The reciprocating steam engine is in many respects excellent for marine propulsion, and the best speed for any given power is closely the same as for the propeller, and consequently no intermediate gearing is necessary.

In some of the early ships the engine speed was so low that gearing had to be introduced to speed up the screw, but this was very soon dropped. The suitability of the direct coupled steam engine may be judged from the enormous number of ships there are fitted with this type of propelling machinery; in fact the inverted marine steam engine has become almost the standard of mechanical practice, and a very large number of engineers to-day have received their training with such types of engines; it has been very ably described by Kipling in "McAndrew's Hymn." The reason why this type of engine is being displaced to-day is, firstly, that for the largest sizes of ships the reciprocating steam engine becomes too large to be practicable, and secondly, the fuel consumption is higher than is required for steam turbines or for Diesel engines. In the reciprocating engine the cylinder is exposed alternately to hot and cold steam, and a considerable amount of condensation takes place, which is to some extent reduced by having multiple expansion; also in this type of engine, high vacuum cannot be utilised as it is not practicable to make the low pressure cylinder sufficiently large to deal with the increased volume of steam occurring with high vacuum. In the steam turbine, the flow of steam is continuous through the turbine, and parts are therefore not subject to alternating temperatures; also the highest vacuum can be readily utilised, and further, superheated steam can be used. For these reasons, the fuel consumption for steam turbines is considerably lower than for reciprocating engines, but in order to obtain these results the steam turbine has to run at a very high rotational speed, and consequently some form of mechanism must be instituted between the turbine shaft and the propeller to reduce the rotational speed.

The Diesel engine at the present moment is rather a clumsy affair, but it has a very high thermo-dynamic efficiency. In this engine, air is drawn in and then compressed to a very high pressure (about 500 lb. per square inch), and in doing this the air becomes so hot that when fuel is introduced into this highly compressed air it immediately burns. The burning of the fuel still further increases the temperature and maintains the pressure during the forward stroke of the piston, so that work is obtained from the engine. Although the compressive maximum pressure is of the order of 500 lb. per square inch, the mean effective pressure is considerably lower, being only about 80 lb. per square inch to 100 lb. per square inch; as a consequence the engine has to be very heavy for the power developed, and most modern engines run at a comparatively low speed. It is suitable for directly coupling to the screw, but it is not self-starting, and starting and reversing have to be carried out by means of compressed air contained in steel bottles. With the possibility of electrical transmission from the engine to the propeller shaft, it would be desirable to design engines to run at high speed, and this should be feasible, as the reciprocating parts being already made to withstand the very high compressive pressure should be amply strong to withstand high inertia stresses. By suitably proportioning the length of stroke and connecting rod, the reciprocating inertia stresses can be made largely to cancel out the compressive stresses.

On account of the reduced size and cost and higher efficiency of steam turbines, most recent large ships have been fitted with this type of propelling machinery. In some of the earlier ships the turbine was directly connected to the propeller shaft, but in doing this the propeller has to run too fast and the turbine has to run too slowly. The Mauretania is one of the best examples of this form of equipment, but it is probable that had

* Paper read before Section G of the British Association at Liverpool, September 19, 1923.

this ship been fitted with propellers and turbines, both of which had their best speed, the propelling machinery could have been reduced to about two-thirds of its present size, and the fuel consumption and boiler equipment to about a half.

The next step was to introduce mechanical gearing between the turbine and propeller shaft, and this is the usual form of propelling machinery to-day. For the larger ships it is sufficient to use a single speed reduction, but for some of the smaller equipments the best speeds for propeller and turbine necessitate a reduction ratio of about 40 to 1, and in this case double reduction gearing is necessary. The results obtained with single reduction gearing have, on the whole, been satisfactory, but with double reduction gearing a certain amount of trouble has been experienced. Accumulated experience with mechanical gearing indicates that the tooth pressure on low speed wheels should not exceed about 600 lb. per inch of face on the wheel, and on high speed pinions the corresponding figure should be 300 lb.

It is probable that the difference between success and failure in gearing depends upon whether there is an actual film of oil between the engaging teeth, or whether these teeth make mechanical contact. If a film of oil can be established and maintained during the time the teeth engage, then they do not actually come into contact, and wear does not take place.

It has been found on large bearings that in order to maintain the oil film, a mean pressure of perhaps 100 lb. to 200 lb. per square inch must not be exceeded, but if a similar bearing could be split up into a large number of faces, each of which takes its share of load, then pressures could be increased to possibly 1,000 lb. per square inch, and the oil film still maintained. Something similar happens with gear teeth.

There are two main reasons why high pressure spots may appear in gearing, that is to say, spots where the pressure is very much higher than the average, and these are faulty alignment, either due to initial incorrect alignment or due to springing of the gear casing or the ships structure, and the inaccurate pitching of the teeth. This inaccurate pitching of the teeth becomes particularly important where the speed of the engagement of the teeth is high. Suppose that a pinion having 50 teeth is running at 3,000 r.p.m., or 50 per second, each tooth is in engagement for $\frac{1}{2,500}$th part of a second. If it is further assumed that such a tooth be displaced from its position by only $\frac{1}{1,000}$th part of an inch, it will be seen that the pinion would have to be accelerated $\frac{1}{1,000}$th part of an inch in a circumferential direction during the very small interval of time during which the tooth is in engagement, and the inertia stresses due to this acceleration may be several times higher than the mean pressure due to the power which the teeth are transmitting. If there is a proper oil film, then it may be capable of absorbing such small irregularities in the teeth, forming, so to speak, a cushion; but if the oil should be squeezed out, then there is a strong likelihood of mechanical wear taking place, and if this starts, the wheels rapidly deteriorate, and have to be ultimately replaced.

Electric Transmission of Power.—This would seem a round-about way at first sight, but it will be shown later that the weight and size of machinery required does not differ greatly from gearing, and it has many distinct advantages. In an electric motor the tangential force causing rotation is magnetism, which acts much in the same way that gravity does, that is, invisibly, and without any apparent means for transmitting the force.

The rotor of an electric motor has this force acting on it. Although mechanically it is perfectly free and not touching anything, the electric currents in the conductors of the stator which surrounds the rotor gives rise to magnetism, which rotates, and in rotating, draws the rotor with it. It can readily be seen with this arrangement that there is no mechanical wear, and an electric motor does not wear out. Also this magnetism is elastic, and consequently the inertia stresses which might be due to any slight irregularity in the speed of rotation do not result in high forces as occurs with gear wheels. The amount of force which can be exerted by an electric motor depends upon how much magnetism can be carried by the iron parts, and how much current can be carried by the copper conductors, but it may be assumed roughly on a motor such as should be used for propelling ships that about 3 lb. tangential pull can be exerted on every square inch of its surface.

Comparison between Gear Wheel and Electric Motor.—Assuming that an electric motor has a rotational force of 3 lb. on each square inch of the rotor surface, and that a gear wheel has a rotational force of 600 lb. on each linear inch of face, a comparison of size can be made. For the purpose an example will serve, and it will be assumed that 3,000 h.p. are required to drive a propeller shaft at 100 r.p.m. The torsional force corresponding to 3,000 h.p. at 100 r.p.m. is 1·9 million inch lb. If d and l are respectively the diameter and length of the gear wheel and the electrical motor, then for the gear wheel the torque or torsional force will be $600 \times \frac{d}{2} \times l = 300\ dl$, and for the motor the force will be $\pi\ dl \times \frac{d}{2} \times 3 = 4{\cdot}7\ d^2l$.

A suitable diameter for an electric motor of this capacity is 130 in. For this diameter the length from the above expressions will be 24 in. for the electric rotor, and 49 in. for the gear wheel. It will be seen that for this diameter the electric motor is smaller than the gear wheel.

If two pinions are fitted to the gear wheel, its length will be halved, but two pinions mean either two turbines —an expensive and not very efficient arrangement for an equipment of this size—or else a double intermediate wheel, an arrangement in which it is difficult to ensure that the pinions share the load equally. Further, the diameter of the gear wheel would probably be reduced somewhat with a corresponding increase in length. The example shows, however, that electric motors can be made comparable in size with gear wheels.

The operation of an electric motor or generator depends on laws of electro-magnetic induction, which were first discovered by Faraday. These laws expressed in general language show that if a piece of iron is surrounded by conductors carrying current, then the iron becomes magnetised and, in fact, any space inside the coil of wire, although the presence of the iron very much increases the amount of magnetism. If a conductor is moved sideways across a magnetic field—a space permeated with magnetism—electro-motive force or voltage will be produced in the conductor. The voltage induced usually causes a current to flow if the electric circuit is a closed one. The conductor must move sideways at right angles to the direction of the magnetism, that is to say, it must cut the magnetism in much the same way as a man would cut off the head of a thistle with a walking stick; the walking stick representing the conductor, and the thistle the direction of the magnetic force. If a conductor is situated in a magnetic field, and has a current flowing through it, then it will experience a mechanical force tending to move it sideways, and the magnetic field will also tend to move in a direction opposite to that in which the conductor moves. Two magnetic poles will attract or repel one another, depending on the direction of the magnetism. In a dynamo magnetic poles must always exist in pairs for the reason that the magnetism which comes out of one must return by the other, and the smallest number of poles that can be fitted to a dynamo is two.

In ship propulsion, usually three-phase alternating electric currents are used. The meaning of this will be understood when it is explained that an alternator, such as is coupled to a turbine, consists usually of two poles which are magnetised by means of a separate source of current supplied by a small dynamo. These magnetised poles revolve at a high speed inside the stator, which consists of laminated iron carrying a lot of electric conductors around the inner periphery. When the pole passes these conductors voltages are produced and currents flow in them. The conductors are arranged in three groups symmetrically placed in such a way that the voltage induced in phase B occurs after phase A, and in phase C after phase B, and so on. Also a conductor which is opposite to a north pole has a voltage of current induced in one direction and in a south pole in an opposite direction. Currents therefore flow in any one phase in any one direction during a half revolution of the machine, and the other direction during the other half revolution.

By means of suitable cables the three groups of phases in the alternator are connected to three corresponding phases on the motor which is connected to the propeller shaft. In the motor, however, instead of having two poles there are probably 60. If the alternator is revolving, and we assume that the maximum current is flowing in phase A, then the same current will flow through phase A on the motor, and the coils on phase A will produce 60 tufts of magnetism or poles on the motor. An instant later the current in A will have decreased, and the current in phase B will have attained its maximum. As phase B is displaced slightly from phase A, the position of the magnetic tufts or poles will move a corresponding amount; similarly when phase C is carrying current the poles will have moved again to correspond with phase C; thus the position of the magnetic poles will be always moving to correspond to phases A, B and C in succession. The rotation of the alternator thus produces a set of 60 poles on the motor whose position is continuously moving; one-half revolution of the alternator will move the pole 1/60th of a revolution on the motor. The rotor of the motor is similar to the rotor of the turbo-alternator. It has 60 poles which are magnetised by direct current from a separated source. It is not very difficult to see that if the stator and rotor both have magnetic poles there will be an attraction between these and if the stator poles tend to move, the rotor poles will be dragged with them.

If the cables of two of the phases are transposed, the sequence of the poles on the motor will be changed. Instead of being ABCABCABC they will become BACBACBAC, and it will be noticed that this is just the reverse sequence; this means that the motor will tend to run in the opposite direction. If the current which excites the magnets is removed, then the magnetism, currents and the mechanical force will disappear and the whole system can be rendered inoperative by simply taking off the excitation current to the magnets. The relative speed of the motor and the turbine depends, as already mentioned, on the relative number of poles. If a motor has 60 poles and the turbo-alternator has two, then the speed of the motor will be 1/30th the speed of the turbine. For example, the turbine may run at 3,000 and the motor may run at 100.

The method of control and reversal is, as follows:—The steam turbine is fitted with a governor by means of which the speed can be varied over a wide range. For starting up, the governor is set to run the turbine at slow speed, about 20 per cent. of normal. The main switches between the motor and alternator are closed and the motor and alternator are then excited, and immediately currents and force are produced which cause the motor to rotate at its corresponding speed. Finally, the speed of the turbine is increased to full value, and the motor speed increased correspondingly. This operation can be understood perhaps more readily if it is compared with the operation of a motor car. The accelerator pedal corresponds with the turbine governor, the clutch corresponds to the excitation and the gear lever to the main switches. If the ship (car) is running full speed ahead, and it is required to reverse it, the foot is first of all taken off the accelerator—the governor is set for low speed running—the clutch is pressed out—the excitation is taken off—the gears are thrown from forward to reverse—the main switches are thrown over. The clutch is let in again—the excitation is re-established—the accelerator is pressed—the governor is put to full speed setting.

In some ships, direct current, that is, a current which flows always in the same direction, is used, but this is only suitable for comparatively small installations. In a direct current generator or motor, the main poles are usually stationary, and are attached to the outer member or stator. By means of brushes bearing on the commutator current is fed into the armature in such a way as to produce a magnetic pole in the armature which is displaced from the main poles; consequently when currents flow in the armature these two poles attract one another and cause the armature to rotate.

The difficulty with direct current machines is that the current has to be reversed by means of carbon brushes in the commutator, and this is only feasible with currents of moderate amount; further than that, owing to the commutator being exposed, it is not feasible to use very high voltages, and consequently the powers that can be used with direct current machinery are usually limited, and such as would be suitable for small ships. The advantage of direct current machinery is that the ratio of speeds between the generator and motor is variable.

Further Considerations of Electrical Transmission Efficiency.—The efficiency of electric transmission is very closely the same as double reduction gearing.

In a paper read by Mr. W. J. Belsey before the Institution of Engineers and Shipbuilders of Scotland, he worked out some examples in which he showed that the losses on turbo-electric equipment were 8·2 per cent., double reduction gearing 10 per cent., single reduction gearing 8 per cent. From the efficiency point of view there are advantages in the electrical equipment which cannot be obtained with the gearing. In general, a single turbine can be used instead of two which saves a considerable amount of loss in the glands, piping, &c. Much higher superheat can be used, which becomes impossible with the geared turbine on account of the reversing blades, and finally the loss associated with the reversing blading is eliminated.

Reliability.—Apart from the bearings which, of course, can be oil film lubricated, there are no wearing parts in the electrical equipment, and provided the equipment is properly designed it should have an almost indefinite life.

Repairs.—Should these be necessary they can readily be carried out, and generally a repair will consist in replacing some of the electrical conductors on which the insulation may have become damaged. This is comparatively a simple matter and can be carried out easily, in fact in most cases such repairs can wait until the ship reaches port.

Ventilation.—The losses which occur become converted into heat, and this heat must be carried away by means of suitable ventilating air; the air may either be drawn from outside and expelled outside again, or the same air used over and over again, and cooled by means of water cooled radiators.

In naval vessels it is often desirable to run at full power or at cruising speed. With electrical transmission this can be carried out by arranging that the motor shall have two sets of poles, which is equivalent to changing the gear ratio; thus, the turbines can be run at full speed when the ship is travelling at a reduced speed, and as the power is very much lower at the reduced speed of the ship some of the turbines may be shut down. This gives a very great gain in economy. This practice has been adopted on most of the American naval vessels.

Although the Diesel engine runs at approximately the same speed at which the propeller runs, still electric transmission can be usefully employed, even on Diesel ships. The advantages are that the engine can be subdivided up into smaller units, and can probably be run at higher speeds. The engines can also be started up light, and once started may be left running even when the ship is standing still. The engines also do not require to run in the reverse direction, as reversing can be done with the electrical equipment.

In the case of the ships being built by Messrs. Cammell Laird and the B.T.H. for the United Fruit Company, a large amount of power is required for the refrigerating plant in addition to propelling the ship. In this case the Diesel engines are fitted with two sets of generators, one being used for propelling and the other for supplying power to the freezing plant. By using direct-current machinery the engines can run at full speed, whatever speed the ship is running at, and therefore full power is always available for the freezing plant.

A very successful example of an alternating-current ship is the San Benito, which also belongs to the United Fruit Company. This ship was built about two years ago by Messrs. Workman Clark & Co., and equipped by the B.T.H. Company, and has been running between Boston and the West Indies very successfully. The engine room staff are delighted with the control, and would be very loath to go back to any other form of propelling machinery.

ELECTRIC MINE LOCOMOTIVES COMPETITION.—The Secretary for Mines, Lieutenant-Colonel G. R. Lane-Fox, M.P., announced recently that Mr. Charles Markham, of Chesterfield, had placed at his disposal 1,000*l.* to be offered as a prize for the best storage battery locomotive for use underground. Judges have been appointed and with the co-operation of H.M. Chief Inspector of Mines, they have drawn up the conditions of the competition. Copies of these can be had by interested parties on application to Mr. A. M. Clegg, Secretary, Electrical Storage Battery Locomotive Competition, Mines Department, Dean Stanley-street, London, S.W. 1.

THE STRENGTH OF FORKED CONNECTING RODS.*

By William J. Kearton, M.Eng., A.M.Inst.N.A.

In many instances of the design of important engine details, the calculations made are based upon well-established principles and accurate assumptions, and the results represent, with a fair degree of approximation, the actual facts. The forces brought to bear on many engine parts are, however, very complex, and in order to obtain even an approximate idea of the stresses induced, certain assumptions have to be made. The doubtful nature of these assumptions often vitiates the calculated results and may even render them valueless, except, perhaps, as means of comparing the strength of parts to be constructed with that of parts which have withstood the test of experience.

From the utilitarian standpoint, such calculations may, and do, have value, but from the scientific point of view they are of little or no interest. In certain instances, the assumptions made are such that the actual stress in the material is greatly in excess of the calculated value. This may, for example, occur when some of the assumed conditions which would tend to ameliorate the hardship experienced by the material are but imperfectly realised. This might be allowed for, when the calculations are merely a basis of comparison, by a ridiculously high "factor of safety"; an obviously unsatisfactory procedure. In other instances, the calculated stresses which finally become the apparent working stresses, are far higher than laboratory tests on the material would indicate to be safe. Here practice or experience leads the way, and an imperfect theory follows, merely to give a formula which may be used, sometimes rightly, sometimes wrongly, as a basis of comparison. This appears to be the case with the forked end of the connecting rod, which is a very important detail of all large steam, gas and oil engines.

Forked connecting rods are of two types; one, in which the gudgeon pin is pressed or shrunk into the forks and forms an important connecting link between the two, and the other type in which the fork has palms which support brasses embracing two halves of a gudgeon pin forged integral with the crosshead. Whilst the first type is undoubtedly stronger, the second type is probably superior from other considerations, and is more extensively employed.

The method of calculating the stresses as outlined by the various authorities may be readily followed with reference to Fig.1 in which the two types of forked end referred to above are shown. We may consider any section of the fork such as B C normal to the locus of the neutral axis.

Let P = total load on rod.
A = area of section B C.
I = moment of inertia of section B C about its neutral axis.

It is assumed that the load P on the rod may be replaced by two simple forces $\frac{P}{2}$ parallel to the axis of the rod and passing through points midway between the inside and outside faces in type A fork and through the centre of the brasses in type B fork.

The force $\frac{P}{2}$ produces a bending moment across the section B C equal to $\frac{P\,a}{2}$, and a force normal to the section equal to $\frac{P\,.\,\sin\theta}{2}$.

Hence the stress at B is equal to

$$\frac{P\,a}{2}\cdot\frac{y_b}{I}+\frac{P\,.\,\sin\theta}{2A}$$

and is compressive.

Similarly the stress at C is equal to

$$\frac{P\,a}{2}\cdot\frac{y_c}{I}-\frac{P\,.\,\sin\theta}{2A}$$

and is tensile when the load on the piston rod is downward, as shown. These stresses are reversed when the load is reversed.

If the section be taken as rectangular, then the maximum stress is equal to

$$\frac{P}{b\,d}\left(\frac{3\,a}{d}+\frac{\sin\theta}{2}\right)$$

The magnitude of this stress varies in the general run of connecting rods from 5,000 lb. to 7,000 lb. per square inch, but Bauer in his "Marine Engines" states that in both large and small marine engines, a stress of 14,000 lb. per square inch has been used successfully in practice. It may be further stated that in a certain naval vessel's engines, the stress in the fork of the connecting rod as calculated by this method was no less than 18,500 lb. per square inch. When it is remembered that this figure represents a fairly rapidly alternating stress, it is hard to believe that the calculated value even approximates to the truth.

Allowable stresses.—It is necessary here to consider very briefly the allowable stresses that may be adopted when the alternating nature of the load and the factor of safety are considered.

When material is subjected alternately to pure tensile and compressive stresses of equal amount there is said to be "complete reversal of stress." When the stress alternates between zero and a certain stress, there is said to be a "repetition of stress." The researches of Wöhler, Bauschinger, Stanton and others have shown that for a given maximum stress and a certain range of stress which exceeds a definite limit, the number of alternations to produce fracture is, to a certain extent, definite and depends largely on the nature of the steel, *e.g.*, whether it is hard or ductile. Again, the experiments of Dr. J. H. Smith seem to show that the rapidity with which the stress changes has some effect on the number of repetitions necessary to cause fracture.

The greatest stress which the material can withstand for an infinite number of complete reversals is referred to as the "reversal limit"; and the greatest repeated stress from zero to maximum tensile which will not fracture the material after an infinite number of alternations is termed the "repetition limit." The word "tensile" is introduced here, because no experiments on the repetition of purely compressive stress have yet been made.

Experiments show that for ductile steels which would be used in the forging of connecting rods, the reversal limit is about one-third and the repetition limit about one-half of the ultimate strength of the material. If we further allow a factor of safety of 3, and assume that the ultimate strength of the mild steel used is 70,000 lb. per square inch, then the following results are obtained:—

	Lb. per Sq. In.
Safe reversal limit	7,780
Safe repetition limit	11,670

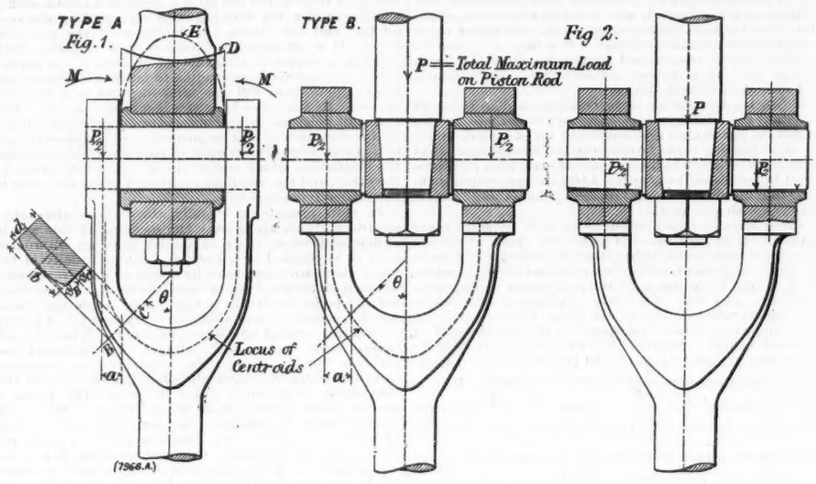
In a steam engine there is a complete reversal of stress once every revolution. In a two-cycle single-acting Diesel engine we have a repetition of stress every revolution. As a matter of fact, the stress never reaches zero, owing to the presence of inertia forces. In a four-cycle Diesel engine there is, during th eworking stroke a change from a maximum compressive to a relatively small compressive stress (at such points as a downward load produces compressive stresses), followed by relatively insignificant complete reversals during the exhaust and suction strokes and then during the compression stroke by a change from a small compressive stress to a maximum compressive stress. It appears, therefore, that so far as the influence of alternating stress is concerned, a single-acting Diesel engine connecting rod is not so severely stressed as that of a steam engine.

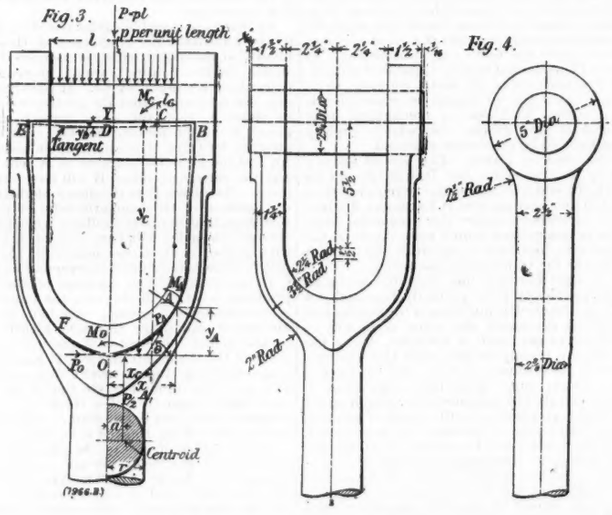
It should be stated that no researches have been made on the repetition of compressive stresses, so that this point cannot be emphasised.

It is the object of this paper to consider the assumption on which the foregoing formulæ are based and to derive a more accurate method of calculating the stresses in the forked end of a connecting rod and, further, to prove the validity of the latter method by experimental evidence.

Examination of Assumptions made in Calculating Stresses.—It is first necessary to consider the assumption that the effects of the force P in the piston rod may be correctly represented by two simple forces $\frac{P}{2}$, as shown in Fig. 1. In type A fork, the gudgeon pin will be strained to some extent by the more or less uniformly distributed load over its length. Although the actual dimensions of the deflection may be quite small, they will have a considerable influence on the stresses in the rest of the fork. For the present, it is sufficient to say that the effect of such strains in the gudgeon pin will be to introduce two bending moments M at the points where the pin is fixed in the fork. Such bending moments will be added to the moments produced by the forces $\frac{P}{2}$, and will obviously tend to neutralise their effects. Thus the bending moment at any section such as B C will be reduced or may even be completely changed in sign. The problem may be considered from another point of view. Such bending moments as $\frac{P\,a}{2}$ at section B C will tend to open out the forks. This is prevented to some extent by a tensile force induced in the gudgeon pin, and such a tensile force will obviously produce at a section such as B C, a moment of the opposite sign to that produced by the force $\frac{P}{2}$.

In type B fork, similar effects are present, but they are not so obvious. In order to show the probable state of affairs, Fig. 2 has been prepared. Here the deflections are considerably exaggerated for the sake of clearness. In the first place the crosshead pin will be deflected upwards at each side, tending to concentrate the heavier pressures in each bearing at the side nearer the piston rod. Secondly, the moments produced by the bearing pressures will tend to cause the forks to open out, thus further concentrating the load over the portion of the brasses nearer the piston rod. Thus the resultant force $\frac{P}{2}$ will not





* Paper read before Section G of the British Association, at Liverpool, September 17, 1923.

pass through the centre of the brass, but probably through some point between the centre of the brass and the piston rod, so that the stresses in the fork, while still indeterminate, are probably much less than those calculated in the usual manner.

The influence of lubrication is relevant to the argument. In a steam engine connecting rod where the amount of lubricant in the bearing is small at any time and in which, judging by the amount of wear which takes place in small ends, there is often semi-metallic contact, the above argument is probably true. In a Diesel engine of the closed type, there is a fairly plentiful supply of oil supplied under pressure to the crosshead bearings, and since an oil film of appreciable thickness would partially or entirely eliminate the effects due to deflection, the above remarks are not quite true.

Method of Calculation.—Whilst it is probably impossible to calculate the stress distribution in a type B fork

I is the moment of inertia of the same section.
E is Young's modulus of elasticity.
s is the distance measured around the curve from O to Y.

It also follows by the same principle, that since the x displacement from O to Y is zero,

$$\int_0^Y \frac{M\,(y_D - y)}{E\,I}\,ds = 0 \quad . \quad . \quad (2)$$

Referring to Fig. 3, we may consider the equilibrium of the right-hand half of the forked end only. The known upward force in the rod is $\frac{P}{2}$, passing through the centroid of the section at a distance $a = \frac{4r}{3\pi}$ from the

$$M_A = M_o + P_o y_A - \frac{P}{2}(x_A - a) \quad . \quad (3)$$

Similarly at a point C on the centre line of the gudgeon pin, the bending moment will be

$$M_C = M_o + P_o y_C - \frac{P}{2}(x_C - a) - \frac{p\,l_C^2}{2} \quad . \quad (4)$$

Hence by equation (1), assuming E to be constant throughout,

$$\Sigma_o^Y \frac{1}{I}\left\{ M_o + P_o\, y - \frac{P}{2}(x - a) - \frac{p\,l^2}{2}\right\}\delta s = 0 \quad (5)$$

and by equation (2)

$$\Sigma_o^Y \frac{y_D - y}{I}\left\{ M_o + P_o\, y - \frac{P}{2}(x - a) - \frac{p\,l^2}{2}\right\}\delta s = 0 \quad (6)$$

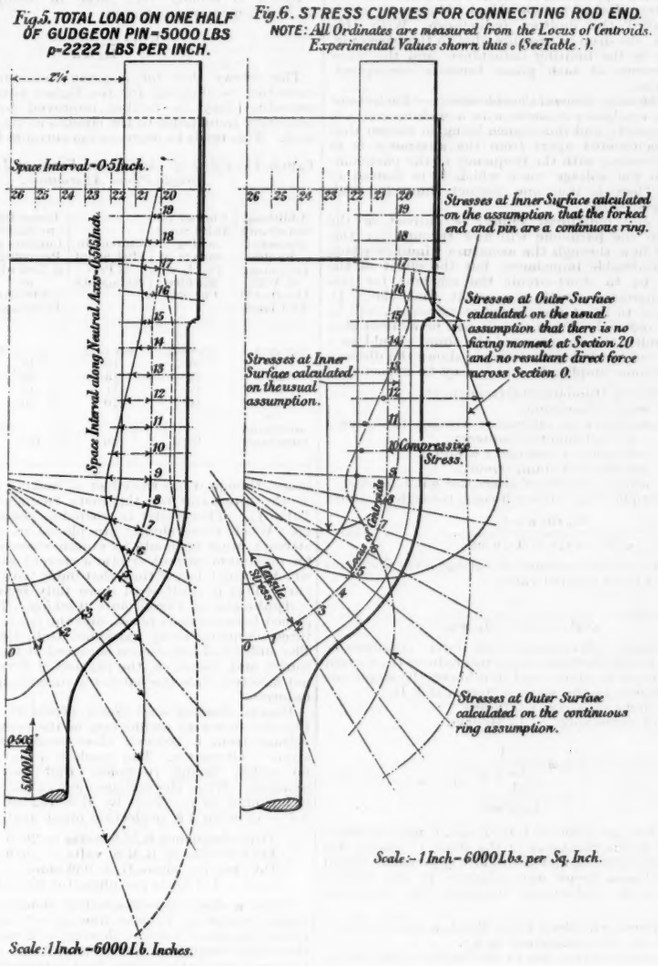


Fig. 5. TOTAL LOAD ON ONE HALF OF GUDGEON PIN = 5000 LBS
p = 2222 LBS PER INCH.
Fig. 6. STRESS CURVES FOR CONNECTING ROD END.
NOTE: All Ordinates are measured from the Locus of Centroids.
Experimental Values shown thus ∘ (See Table.).
Space Interval = 0·5 Inch.
Space Interval along Neutral Axis = 0·515 Inch.
Stresses at Inner Surface calculated on the assumption that the forked end and pin are a continuous ring.
Stresses at Outer Surface calculated on the usual assumption that there is no fixing moment at Section 20 and no resultant direct force across Section 0.
Stresses at Inner Surface calculated on the usual assumption.
Compressive Stress.
Tensile Stress.
Locus of Centroids
Stresses at Outer Surface calculated on the continuous ring assumption.
0·5 Cos θ
5000 Lbs.
Scale:- 1 Inch = 6000 Lbs. per Sq. Inch.
Scale: 1 Inch = 6000 Lb. Inches.

NOTE TO FIG. 5.
Full Line Curve shows Bending Moments calculated on the assumption that the Forked End and Pin are a continuous ring.
Broken Line Curve shows Bending Moments calculated on the assumption that there is no fixing moment at Section 20 and no resultant direct force across Section 0.
All ordinates measured from the neutral axis.
(1263 c)

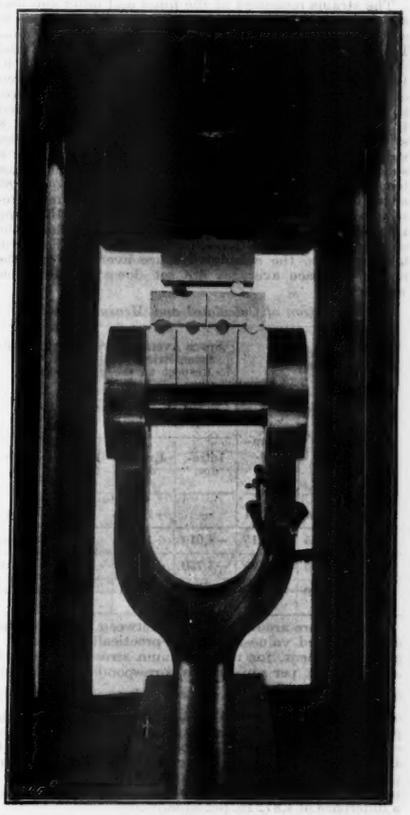


FIG. 7.

owing to the above considerations, the other type is more amenable to calculation, and the following remarks apply entirely to a fork of the A type.

Let O A B D E F (Fig. 3) represent the locus of the traces of the neutral axes of the fork sections on the plane of the paper (which is the plane of the bending moments) when the fork is considered as a continuous ring attached to, but merely supported by, the rod. The full line represents the unstrained condition, and the broken line is intended to show, in an exaggerated manner, the position taken up by the neutral axis when the fork is supporting its working load. It is obvious that O Y is an axis of symmetry. Hence, if the load is symmetrically disposed with respect to the centre of the rod, the tangents at O and Y are parallel. Therefore, by the "Principle of Continuity" we have:

$$\int_0^Y \frac{M}{E\,I}\,ds = 0 \quad . \quad . \quad (1)$$

Where M is the bending moment at any section.

axis of the rod. This is balanced by the uniformly distributed load on the gudgeon pin.

The actual distribution of the load on the crosshead pin is a matter of some doubt. Without any lubrication whatever, it is probable that, owing to the deflection of the pin, the pressures would be concentrated at the ends of the brass and the distribution of load would be somewhat as shown by the curve D, in Fig. 1. In a perfectly lubricated bearing, the pressure is necessarily zero at the ends of the bearing surface and the pressure distribution as indicated by the experiments of Beauchamp Towers would be as shown by the curve E in Fig. 1. In an actual case, the pressure distribution would probably be sensibly uniform. This has been assumed in the calculations and imitated in the experiments.

There will be some unknown direct force P_o and an unknown bending moment M_o exerted by the left-hand half of the fork on the right-hand half across section O. The shearing force across the section O is, of course, zero. Then at a point A on the neutral axis, the bending moment will be

The solution of equations (5) and (6) gives the two unknowns P_o and M_o, and these enable one to calculate the bending moment at every section.

The following calculations were made upon a small marine engine connecting rod originally intended for an early destroyer. The dimensions of the forked end are given in Fig. 4. A full-size drawing was made and a number of suitable sections chosen to determine the neutral axis. The total distance along the curve O A B between O and B was then divided into 20 equal intervals, and the distance from B to Y into 6 intervals. The integration represented by equations (5) and (6) above was then performed arithmetically by the use of Simpson's rule, the assumed value of P being 10,000 lb. The result of this calculation was a simultaneous equation in P_o and M_o, giving $P_o = 428$ lb., and $M_o = 8{,}560$ in.-lb.

The resultant bending moments were then calculated and plotted to scale in Fig. 5. On the same diagram is shown a curve of bending moments calculated on the usual assumptions as mentioned earlier in the paper. It will be noticed, that between sections 6 and 17 the bending moments calculated by the two methods are actually of opposite sign, and that at section 1, the bending moment calculated by the method proposed is only 69 per cent. of that calculated by the former method.

Across each section in addition to the bending stresses there is a uniform stress due to a normal force P_A (see Fig. 3).

$$P_A = P_o \cos\theta + \frac{P}{2}\sin\theta.$$

The resultant stresses are plotted to scale in Fig. 6. Here, again, a comparison is made of the results of the two methods of calculation. It appears that sections 2 and 9 are the two weakest sections of the fork. At section 2 there is a stress of 4,823 lb. per square inch at the outer surface, and at section 9 a stress of 4,486 lb. per square inch at the inner surface.

Experiment.—In order to test the agreement of the

calculations with facts, the above-mentioned connecting rod was subjected to a compressive load in a Buckton testing machine. The following method was adopted for applying a uniformly distributed load to the pin, and will be readily understood with reference to the photograph, Fig. 7. The load was applied to a slightly rounded projecting ridge at the top of a small cast-iron block and at the centre of its length. This force was then equally distributed between two cast-iron blocks, the force being transmitted through rollers resting in V-grooves cut in the top surface of the latter blocks. The load on each of these blocks was then equally divided and transmitted to saddle pieces by rollers resting in V-grooves cut in the upper surface of the saddle pieces. The four saddle pieces were machined from two square blocks of cast-iron accurately bored to the same diameter as the gudgeon pin, and further to ensure a uniform distribution of the load, paper was inserted between the saddle pieces and the pin.

The strains measured at the inner and outer surfaces and for each side of the fork, were obtained by means of a Martens extensometer over a gauge length of 50 mm. The stress was calculated directly from the measured strain, assuming that E was 30×10^6 lb. per square inch. It will be apparent that the strain can only be measured over surfaces with a reasonably large radius of curvature, so that the experimental measurements were limited to the straight portion of the rod between sections 8 and 15. It will be further apparent that the stress calculated from a measurement of the strain will be a space average of the stress for all points within the gauge length of the extensometer, *i.e.*, 50 mm. or about 3·82 space intervals. Hence the most satisfactory measurements could be made between sections 9 and 15 (using this distance as a gross length) between which the calculated stress variation is fairly uniform. The calculated stresses, the calculated space averages, and the measured space averages are set down in the table annexed.

Comparison of Calculated and Measured Stress.

Sect. No.	Calculated Stress.		Space Average of Stress for Space Symmetrically Disposed with Respect to the given Section.			
			Calculated.		Measured.	
	Intra-dos.	Extra-dos.	Intra-dos.	Extra-dos.	Intra-dos.	Extra-dos.
9	−4,486	+1,594	—	+1,275	—	+1,145
10	−4,265	+1,215	−4,010	+1,150	−4,315	+1,005
11	−3,885	+ 795	−3,750	+ 765	−3,925	+ 910
12	−3,520	+ 380	−3,520	+ 380	−3,360	+ 137

Whilst there are discrepancies between the calculated and measured values, there is, practically speaking, a good agreement, for the maximum stress difference is about 300 lb. per square inch corresponding to a strain of $\frac{1}{100,000}$. The great difference between the results obtained by the generally accepted method and the proposed method of calculation may be appreciated by comparing the stresses at the outside surface at section 8. By the "old" method of calculation we obtain a compressive stress of 3,421 lb. per square inch; by the "new" method, the stress is 1,451 lb. per square inch tensile; a difference of 4,872 lb. per square inch.

Possible causes for the slight discrepancies are the point of discontinuity at section 20 and the overlapping of sections between 17 and 21.

Whilst the stresses in the straight portion of the fork calculated by the two methods are of opposite kind, there is for the example considered not a great difference in the magnitude. With a change in the general proportions, the difference in the magnitude of the stress in this part might be considerable. At the section near the junction of the fork and rod, both methods of calculation give a compressive stress at the outer surface and a tensile stress at the inner surface, but the stress calculated by the proposed method is only about 60 per cent. to 65 per cent. of that calculated in the usual way.

In conclusion the writer hopes that this paper will shed a little light on an interesting problem, and he considers that it does much to explain away the apparent anomaly that an overstressed material could be used year in and year out without a sign of failure. He would like to express his thanks to Professor Watkinson for permission to carry out the experiments and to Mr. W. Donaldson and Mr. W. G. Pullen for their very kind assistance in the preparation of the apparatus.

The China Year Book.—The compilation of an annual reference book must be a laborious task, but in China where the Central Government has exercised no real authority over the provinces, the difficulties must be almost insuperable. In spite of that, Mr. H. G. W. Woodhead, the editor of the *Peking and Tientsin Times*, has produced a very valuable encyclopedic work dealing not only with commercial statistical and manufacturing returns, but also with the geography, geology, flora and fauna. The bringing together of the provisions, regarding Far Eastern questions, decided upon at the Washington Conference, and also the agreements reached after the Shantung negotiations dealt with in the concluding chapters, gives the work an added value to all interested in China. The issue for 1923 was recently published by Messrs. Simpkin, Marshall, Hamilton, Kent and Co., Limited, London, at a price of 35*s.* net.

A METHOD OF IMPROVING THE VOLTAGE WAVE SHAPE OF AN ALTERNATOR BY EXTERNAL CIRCUITS.*

By Professor E. W. Marchant and T. H. Turney, B.Eng.

In some cases it is necessary to secure an accurate sine shape for the wave form of an alternator. The best means of securing this is to design the machine in such a way that no harmonics of pressure are present in the curve. In some cases where machines have already been designed, and it becomes important to ensure that the wave shape shall have irregularities taken from it, a method of eliminating the irregularities may be of use. The principle involved in the method herein described is to short circuit each phase of the alternator for the frequency of the ripple which it is desired to eliminate, by introducing a shunt which is in resonance with the frequency of the ripple, and to cut down the short-circuit current by introducing an additional inductance, which may be called the limiting inductance. With this arrangement, the drop in pressure, due to the harmonic, is taken up in the limiting inductance, and the wave shape of pressure of each phase becomes correspondingly improved.

Design of Shunts—General Considerations.—Each shunt consists of a condenser in series with a choking coil, the values of capacity and inductance being so chosen that the shunt considered apart from the alternator is in electrical resonance with the frequency of the particular harmonic in the voltage wave which it is desired to eliminate. There is thus one distinct shunt for each harmonic dealt with.

Consider any individual shunt; a current of the frequency of the harmonic will flow through it; this current will flow through the armature windings which have a considerable impedance, but the effect of the shunt will be to short-circuit the machine for this particular harmonic, with the result that the P.D. variation due to it, at the alternator terminals, will be very much reduced. From this, it will be evident that for best results, the resistance of the shunt should be a minimum, and the following formula shows the diminution in harmonic amplitude, which may be expected.

Let $\omega = 2\pi \times$ (fundamental frequency).
n = order of harmonic.
$L_A \omega$ = reactance of alternator winding to currents of fundamental frequency.
R_a = resistance of alternator winding.
r = resistance of shunt circuit.
E_n = nth component of alternator e.m.f. wave.

The amplitude of the current flowing through the shunt

$$= \frac{E_n \sin n\omega t}{\sqrt{(R_A + r)^2 + (L_A n \omega)^2}} \quad . \quad . \quad . \quad (1a)$$

and the ratio of the harmonic of voltage after the shunt is connected to its original value

$$= K_n = \frac{r}{\sqrt{(R_A + r)^2 + (L_A n \omega)^2}} \quad . \quad . \quad (1)$$

It is clearly advantageous to have considerable impedance in the alternator, since this reduces the current passing through the shunt, and thus lowers the amplitude of the harmonic in the wave of terminal P.D.

Let shunt capacity = C farads.
Shunt inductance = L_S Henrys.

If

$$C n \omega = \frac{1}{L_S n \omega}$$

$$C = \frac{1}{L_S n^2 \omega^2} \quad . \quad . \quad . \quad (2)$$

Hence when any value of L is chosen, C may be determined. Now the resistance of the shunt is mainly due to the inductance coil, and not to any appreciable extent to the condenser, hence any reduction in the number of turns on the inductance improves the correction factor K_n.

Current Flowing in Shunt due to Fundamental E.M.F.—Let amplitude of fundamental be E_1.

Let I_{1s} be the current due to the fundamental voltage wave which will flow in a shunt tuned to nth harmonic. Then

$$I_{1n} = \frac{E_1}{\sqrt{\left\{\frac{1}{C\omega} - (L_A + L_S)\omega\right\}^2 + (R_A + r)^2}} \quad (3)$$

Now in the denominator of this expression, the largest term is $\left\{\frac{1}{C\omega} - (L_A + L_S)\omega\right\}^2$ and as L_A is very small compared with L_S, we may say that

$$I_{1N} = \frac{E_1}{\frac{1}{C\omega} - L_S \omega} \quad . \quad . \quad (4)$$

We have from equation (2) above $L_S = \frac{1}{n^2 \omega^2 C}$.

Hence

$$I_{1s} = E_1 C \omega \left(\frac{n^2}{n^2 - 1}\right)$$

It will be seen, therefore, that current I is proportional to the capacity C, and from this consideration it would be desirable to decrease C and increase L_S. If C is made too small, however, the voltage on the condenser due to the current corresponding with the ripple with which the circuit is in resonance, becomes too large.

The inductance coil must be so designed as to have the greatest inductance with the smallest possible resistance. This result can only be achieved by using a coil having a very large section of copper, and the extent to which the harmonic of E.M.F. is eliminated depends almost entirely on the weight of copper that is used in the shunt coils.

Currents may flow in one shunt due to a harmonic which is dealt with by another shunt, but these currents will be negligibly small for two reasons. Firstly, when all the shunts are in, the amplitude of the harmonics is greatly reduced, and secondly, the impedance of the shunt to any harmonic other than the one it is designed to eliminate, is very great.

Correction Factor K_n.—

$$K_n = \frac{r}{\sqrt{(L_A n \omega)^2 + (R_A + r)^2}} \quad . \quad (1)$$

(See above).

$L_A n \omega$ is usually very large in comparison with $R_A + r$, hence approximately

$$K_n = \frac{r}{L_A n \omega}$$

This shows that for a given inductance a better correction is obtained for the higher harmonics. The correction may be further improved by placing an additional inductance in the circuits as shown in Fig. 1, at A. This tends to decrease the currents flowing in the shunt, though it has the effect of making the regulation of the alternator for the main frequency worse (see Table I). This matter is treated in greater detail later on. When these shunts are placed in the circuit no attempt must be made to obtain resonance by tuning for maximum current or else a current will be obtained which is much larger than that indicated by the formula (1*a*). This is dealt with more fully below.

Table I.—*Effect of Additional External Inductances in Single-Phase Alternators.*

Additional Inductance measured by the percentage of Volts Absorbed at Full Load.	Current in Third Shunt as Percentage of Full Load Machine Current.	Current in Fifth Shunt as Percentage, &c.	Losses Due to Shunt Currents as Percentage of Loss with no Additional Inductance.	Regulation of Alternator Assuming. 20 Per Cent. Normal.
per cent.	per cent.	per cent.	per cent.	per cent.
5	26·7	16	45	25
10	22	13·3	30	30
15	19	11·5	18	35
20	16·7	10	10	40
No additional inductance	33·3	20	100	20

Application to Three-Phase Working.—The shunts are placed between each phase, and the neutral, there being three shunts for every harmonic dealt with (see Fig. 2). The additional inductance is placed at the star point as shown and, therefore, the regulation between phases is not affected while the harmonic currents may be greatly reduced.

Results obtained with Some Machines under Test.—Fig. 3A, shows an oscillogram of the open-circuit phase voltage from a 200-volt three-phase Swedish "Wenstrom" alternator. The machine runs at 720 r.p.m., 60 cycles, having 10 poles. Full load current = 10 amperes. When the voltage wave in Fig. 3A is analysed it is found to be given by $E = 132 \sin\theta - 37{\cdot}6 \sin 3\theta - 13{\cdot}6 \sin 5\theta$, neglecting phase angle of harmonics.

Triple frequency R.M.S. volts = 26·6.
Fifth frequency R.M.S. volts = 9·6.
D.C. res. per phase R_A 0·056 ohm.
$L_A \omega = 1{\cdot}1$ ohms per phase for 60 cycles.

When a shunt is connected as shown in Figs. 2, the triple frequency current flowing = 7 amperes. Five times frequency current flowing = 2 amperes. When the triple frequency shunts are placed in circuit, the voltage wave for the phase alters to that shown in Fig. 3B where it will be seen that the fifth harmonic remains while the third harmonic is wiped out. Fig. 3C shows the voltage wave for one phase when all three phases have shunts for the third and fifth harmonics and additional inductance is placed in the neutral. A comparison of Figs. 3A and 3C shows that the method reduces the wave of P.D. to an almost pure sine shape. By adding inductance in the neutral, the currents through the triple frequency shunts may be further reduced.

The next machine tested was a 20-k.w.a., 25 cycles single-phase alternator, 200 volts, full load current 100 amperes. In the open circuit voltage wave, there is a prominent 17th harmonic due to the slots. A shunt was made up by using an air core choking coil, $L_s = 2{\cdot}8$ millihenrys, and a battery of Helsby condensers. The current through the shunt was 19 amperes. The wave shape with this shunt in is improved, but there is a ripple left; this ripple has a large amplitude on one part of the wave and a small amplitude on the other part of the wave. This effect is due to the presence of two harmonics of slightly different frequency. A shunt was, therefore, designed with another air-choking coil ($L_s = 1{\cdot}3$ mh.), to absorb this, a 13th harmonic and the corrected wave is of almost pure sine shape. An extra inductance was used to limit the shunt current as follows: With this inductance the R.M.S. value of the two shunt currents amounted to 21 amperes, and the regulation was 10 per cent. with 50 amperes non-inductive load.

With extra inductance the regulation was made worse, the voltage on 50 amperes dropping to 170, or 15 per cent. regulation, but the R.M.S. value of the two shunt

* Paper read before Section G of the British Association at Liverpool, on September 19, 1923.

currents was only 9 amperes. The power loss decreased from 600 watts to 200 watts with this extra inductance. The decrease in the rating of the machine when the shunts are introduced and the shunt currents reduced to 9 amperes, is less than 0·4 of 1 per cent. for the full load current of 100 amperes.

The next machine tested was a 1-kw. Conz high-frequency alternator, 100 volts, 10 amperes 400 cycles to 500 cycles per second. The open circuit wave form, when analysed, consists of the fundamental, together with a second and fifth harmonic. The air core inductances mentioned in the previous test were here used, and a fairly good wave shape was obtained when two shunts were put in. However, the currents flowing in the shunts were too large to make the arrangement practical, as the shunt currents very nearly equalled the full load current of the machine, further the capacity current flowing, due to the fundamental, magnetised the fields and caused a rise in voltage, and the machine became unstable, the alternator behaving in a very similar way to a shunt-wound direct-current machine working on the straight part of its characteristic curve. An additional inductance was, therefore, placed in circuit to diminish the shunt currents. This caused partial resonance to be obtained with the fundamental, and a heavy current flowed in consequence. When the value of this inductance was increased past the resonant point, the regulation of the machine was so poor that it would not be practicable to obtain full load current with this arrangement. The method, therefore, is not very suitable for use with small power high-frequency alternators. The last machine dealt with was a single-phase, 10-pole 50-cycles "Brush" alternator, wound for 200 volts, 60 amperes. Fig. 4A shows the open circuit voltage wave which, when analysed, is given by $V = 191 \sin \theta + 28 \sin 3\theta + 51{\cdot}5 \sin 5\theta$, neglecting the phase angles of the harmonics. Impedance of alternator $L\omega = 0{\cdot}95$ ohm, shunt current approximately 10 amperes for 3rd harmonic and 10 amperes for 5th harmonic. When an additional inductance is put in, the sum of the two shunt currents decreases to about 4 amperes, and Fig. 4C shows the corrected voltage wave which is a quite good shape. It is important to note that when the shunts are arranged as described above, the values of L and C must be determined separately and adjusted as in equation (2). By reducing the inductance in the circuit, a very much larger current than that indicated by equation (1) may be obtained, and the reason for this is that the inductance of the alternator windings forms part of the resonant circuit, and the current flowing under these conditions is very large.

Further, this large current causes a voltage rise in the alternator winding so that the amplitude of the harmonic of voltage measured at the terminals of the machine increases. This effect is seen in Fig. 4B, which shows a curve of worse shape than Fig. 4A.

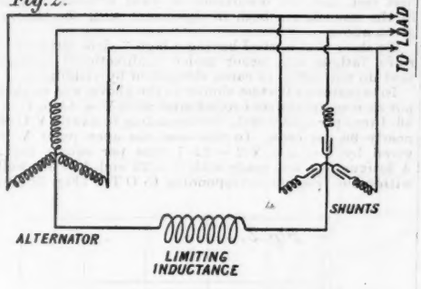
When an iron-cored coil is employed in the shunt circuit, care must be taken that it has the right value of inductance when carrying the current which is expected to flow when the shunt is in use, or the inductance may decrease for large currents due to saturation of the iron, and diminish the effectiveness of the shunt. It follows, therefore, that iron-cored inductances are not very satisfactory for this service, since they will not give good wave shape correction for varying loads on the alternator. The heating in the armature due to the resultant current I may be found from the formula: $I = \sqrt{I_1^2 + I_3^2 + I_5^2 + \&c.}$ A shunt current say, 20 per cent. of the full load current, will, therefore, only reduce the armature rating by 2 per cent.

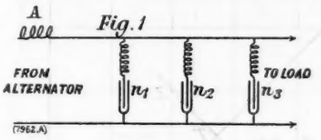
The energy loss in the shunt circuit depends on its resistance and the current flowing through it; by adding inductance, the shunt current is decreased and the loss correspondingly diminished. There is also a waste of energy due to iron losses in the cores of the inductances, and it is essential, therefore, to reduce these as much as possible. Eddy current loss in adjacent current masses may cause serious increase in the effective resistance of the circuit owing to the high frequencies of the currents passing, and care should be taken to minimise this loss. In one case an iron clip on one of the inductance coils caused a large additional energy loss and excessive local heating. For power station purposes some of the additional impedance required might be obtained by using the air core reactances which are generally put in the circuit of the alternator to guard against excessive current due to short circuits. The limiting inductance is very necessary when it is desired to deal with a third harmonic on a three-phase alternator, for it has been shown* that the ampere turns due to the three-triple frequency currents in the phases, neutralise each other, and the armature inductance is, therefore, due only to the leakage reactance. Consequently, the correction obtained is not so complete as it is with harmonics whose frequencies are not a multiple of three times that of the fundamental.

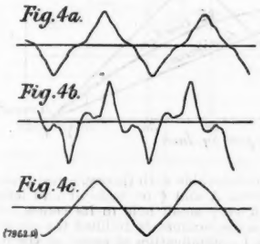
It was found with the three-phase machine tested that an increase of 60 per cent. in the current passing through the third harmonic shunt was recorded when all three phases were shunted, as compared with the current passing when the circuit to the shunt in only one phase was closed. The effect of adding the extra inductance is as shown in Table I, which gives the circulating currents, the losses and the regulation for various values of added reactance for a single-phase machine. An amplitude of 10 per cent. of the fundamental is assumed for each harmonic, and the armature impedance is assumed to absorb 10 per cent. of the generated E.M.F. on full, non-inductive load.

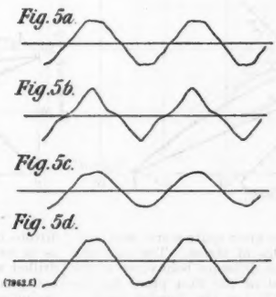
Alternators on Load.—When an alternator is loaded

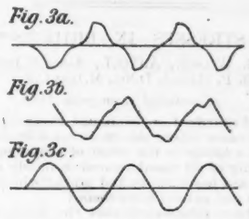
Fig. 2.











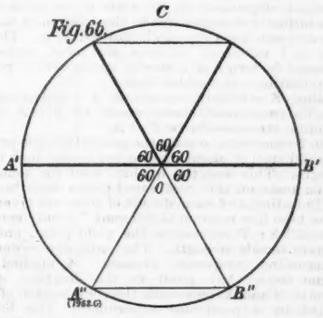


TABLE II.—*Effect of Load Current on Amplitude of Third Harmonic A.S.E.A. Alternator.*

Current in Third Harmonic Shunt. Amperes.		Load Current of Machine. Amperes.
4	..	0
7	..	20
10	..	40
13	..	60

TABLE III.—*Effect of Decreasing Excitation of A.S.E.A. Machine.*

Terminal Volts.		Current in Third Shunt. Amperes.
200	..	13
150	..	12·5
100	..	11·5
60	..	11

* See *Electrician*, 1909, vol. lxiii, page 674. Catterson Smith and E. W. Marchant on "Triple Frequency Currents in Neutrals of Three-phase Star Connected Alternators."

the terminal voltage wave form is generally different from the open circuit voltage wave. This is due to distortion of the field produced by the armature ampere turns, and it would be expected that if a machine on load developed a harmonic which was absent or nearly so at no load, that the amplitude of the harmonic in question would be proportional to the armature current at intermediate loads, and would not be affected by a change in the field exciting current. That this is actually the case is shown below. Fig. 5A shows the O.C. phase voltage wave of a 50-cycles 200-volts three-phase alternator made by the A.S.E.A. of Sweden. When working on full load of 58 amperes per phase, unity power factor, the terminal voltage wave alters to that shown in Fig. 5B. The O.C. wave is a fairly good sine curve with small third and fifth harmonics in it as given by the equation, $E = 116 \sin \theta - 3{\cdot}45 \sin 3\theta - 1{\cdot}5 \sin 5\theta$ (neglecting phase angles). The load curve has the equation: $E = 115 \sin \theta - 28 \sin 3\theta - 5{\cdot}6 \cos 5\theta$ (neglecting phase angles), showing that the third harmonic has increased enormously, and when a shunt is put in circuit to remove this harmonic, there is still a ripple which is due to another higher harmonic. When a second shunt is put in to remove this, the curve shown in Fig. 5C is obtained. On no load the wave form with the shunts in is given by Fig. 5D, and at intermediate loads the currents in the third harmonic shunts are proportional to the armature load current as shown in Table II. Decreasing the field excitation does not diminish the value of the harmonic appreciably, if the armature load is kept constant, as shown in Table III.

In general the harmonics in the wave form of a loaded alternator may be separated into two groups, first those which are produced directly by the field form and conductor grouping and which, therefore, occur at no load and do not alter with load, and secondly, those which are due to distortion of the field by the armature currents, and whose values are proportional to the armature currents. If a machine has two opposing harmonics of the same order, one in each class, then it may happen that the resultant value of that harmonic may be a maximum at no load and a minimum or even zero at full load. In the case of the above machine, the two harmonics are in phase and the value of the resultant harmonic grows as the load increases. This effect does not preclude the use of this method of improving the wave shape, for if a shunt is designed for the maximum value ever attained over the whole range of load for each harmonic in the voltage wave, that wave will be corrected successfully at all loads. As the load changes, the currents in the shunt, of course, will change, but there will always be a constant fundamental frequency current from the alternator. From the above it follows that the maximum value of any harmonic is likely to occur either at no load or at full load, and it would be sufficient to take an oscillogram at no load and one at full load, analyse both, make a list of the harmonics in each, and design a shunt for each harmonic observed, bearing in mind that if the same order of harmonic occurs in both groups, it is sufficient to design a shunt for the one which has the greater amplitude.

In the design of each shunt, the order of the harmonic will determine the value of the product of the capacity and inductance, and the amplitude of the harmonic will give the maximum current which will flow, see formula (1A), and the inductance L_s must be designed to carry this current. The ratio of the capacity to the inductance is determined by the fact that the current (I) through the condenser C, must be such as not to produce higher voltage than its safe working pressure.

From the foregoing analysis of the method, it will be seen that under normal circumstances, the correction of a wave shape may be affected by the arrangement described above, without altering the design of the alternator or decreasing its rating to any appreciable extent.

APPENDIX A.

On the Features of the Design of Alternators which Govern their Terminal Voltage Wave Shape.—The E.M.F. generated in a single conductor will be a pure sine wave if there is a pure sine wave of flux along the air gap, and under these conditions the terminal no load voltage wave shape will be a pure sine also, the amplitude of which, however, will not be the arithmetical sum of the amplitude of the E.M.F.'s generated in each conductor, but will be a rather smaller quantity depending on the distribution of the winding.

The ratio of $\frac{\text{Terminal volts}}{\text{Sum of volts in separate conductors}} = \text{D}.$

D is called the distribution factor of the winding. For an evenly distributed three-phase winding, D is the ratio of the chord A B to the arc A B in Fig. 6A, and this ratio is = 0·956. For a third harmonic, however, this ratio D is the ratio of a diameter to a semi-circular arc, and is = 0·636, and for a fifth harmonic the distribution factor will be = 0·191, as shown in Fig. 6B.

This shows that, given a flux wave with harmonics in

from 15 ft. to 358 ft. on the North Western Railway, the Committee are of opinion that, although these tests do not afford sufficient information to warrant their recommending any modification of the Pencoyd formula for impact at present—the records indicate that a single load concentrated at the main driving axle of each engine passing over a bridge, more accurately represents the true allowance for impact than a uniformly distributed load. The Committee are also of opinion that many more tests are required before a scientific formula covering all sources of impact can be evolved."

Dates.	Weight on Middle of Beam.	Deflection.	Number of Changes	Stresses given by Fairbairn in Bottom Flange.		Stresses in Bottom Flange calculated by Moment of Inertia. Tons per square inch.					Remarks.
				On Gross Area.	On Net Area.	On Gross Area.	On Net Area.				
							Method I.		Method II.		
	Tons.	Inch.		Tons, Sq. in.	Tons, Sq. in.		(a)	(b)	(a)	(b)	
March 21 to May 14, 1860	2·96	0·17	596,790	4·62	6·25	4·66	6·21	6·85	5·36	6·86	
May 14 to June 26	3·50	0·22	403,201	5·46	7·39	5·51	7·35	7·96	6·34	6·86	
July 25 to July 28	4·68	0·30	5,175	7·31	9·88	7·37	9·83	10·51	8·47	9·06	"Broke by tension a short distance from the middle of the beam."
		Total	1,005,175								
Beam repaired, August 9, 1860 ..	4·68	—	158	7·31	9·88	7·37	9·83	10·51	8·47	9·06	"The apparatus was accidentally set in motion." "With this weight the beam took a large but unmeasured set."
August 11 and 12 ..	3·58	0·22	25,742	5·59	7·56	5·64	7·52	8·17	6·48	7·04	
August 13 to October 16, 1861	2·96	0·17	3,124,100	4·62	6·25	4·66	6·21	6·85	5·36	5·90	
October 18, 1861, to January 9, 1862	4·00	0·20	313,000	6·25	8·45	6·30	8·40	9·23	7·24	7·96	"Broke by tension as before, close to the plate riveted over the previous fracture."
		Total	3,463,000								

APPENDIX.

Fatigue Test of a Riveted Girder 20 ft. long, made by Sir William Fairbairn.

Particulars of the experiments are given in the Report published by the Board of Trade* in 1864, and additional information will be found in various papers and in Fairbairn's books.

The results of the tests and calculated stresses are given in the following table.

It is unfortunate that exact details and observations of this very remarkable fatigue test are not on record. Full details of the girder are not available. The plates attached to the Board of Trade Report have been assumed correct in preparing Figures 6, 7 and 8. The total weight is given by Fairbairn as 7 cwt. 2 qr., but the weight of the girder shown (assuming the stiffeners to be double 3 in. × 1½ in. × ½ in. toes joggled on to the main angles) is below that figure.

The rivets were ½ in. diam. and arranged as shown in elevation, the pitch would be about 4½ in. The arrangement of riveting in the flanges is not shown. In estimating the net area of the bottom flange, it has been assumed that there were two rivets in line breaking pitch with the rivets in the vertical legs of the angles. It is important to note, however, that in Fairbairn's calculations of the stresses in the net area he has deducted 0·625 sq. in. which is the area of the three rivet holes.

The stresses given in the table have been calculated in the following ways:—

Fairbairn's by the formula:

$$\text{stress} = \frac{l\,w}{4\,a\,d}$$

l = span in inches, taken as 240, the clear span.
w = the weight at the centre in tons.
d = over all depth (16 in.).
a = area of the flange, the total sectional area of the plate and two angles (2·4 sq. in. gross, 1·775 sq. in. net.).

Method I (*a*) by moment of inertia, ignoring the rivet holes and then increasing the stress in the ratio of the gross to net areas. Two rivets allowed for. The span of girder taken as 21 ft.

Method II (*a*) by moment of inertia calculated with the two rivet holes out. Span, 21 ft.

The testing arrangements were intentionally made so that the load should be applied with a jarring effect and under (*b*) of Methods I and II an increase of from 7 to 10 per cent. is made for the velocity with which the load was probably applied.

Illustrations of the testing arrangements indicate that the load was applied to the bottom flange, as shown in Fig. 8. Severe secondary stresses must have been set up in the flange with every loading, and although the calculated stresses required to cause failure were comparatively high, they would probably have been much higher had the load been applied to the top flange. The distance from the centre of the point where the flange failed is not recorded.

The endurance of some of the rivets is remarkable. In referring to the first test, Fairbairn writes "It is satisfactory here to observe that during the whole of the 1,005,175 changes none of the rivets were loosened or broke." At the centre of the beam the rivets holding the lower angles to the web must have been very severely loaded. The 4-ton load, if taken by the three nearest rivets would give a bearing pressure of 21·3 tons per square inch, but a shearing stress of only 3·4 tons per square inch.

A second experiment was made on the same beam. It was "repaired by replacing the broken angle irons on each side, and putting a patch over the broken plate equal in area to the plate itself." The results of the second tests are given in the table.

* Report of Mr. Fairbairn to the Board of Trade, Command Paper 1864.

THE ENGINEERING POSITION IN GERMANY.—H.M. Consul-General at Cologne has forwarded to the Department of Overseas Trade a report from the *Deutsche Bergwerks Zeitung*, of September 4, which states that under the influence of the renewed and terrific depreciation of the mark the position of the machine building industry as compared with the preceding month became considerably more unfavourable. In numerous works the number of workers was far in excess of requirements, but, owing to legal provisions, the necessary retrenchment could only be accomplished by the introduction of short time. Wages and salaries were adapted to the depreciation of the mark, and increased costs of living by repeated tariff increases, and, in consequence, in several districts, more particularly in the Occupied Territories, they now exceed pre-war values. The discontent among workers brought about by wage disputes was aggravated by the extraordinary shortage of currency for wages, and this induced a section of workers to adopt a policy of passive resistance, a measure which was replied to by certain works by temporary lock-outs. In many districts it was noticeable in August that the supply of raw materials and fuel, more particularly coke and pig-iron, was more unfavourable, which is chiefly attributed to the barrier around the Ruhr which threatens to be still further strengthened in the near future. The position is characterised by the general and considerable falling-off of orders and inquiries both from home and abroad. The slight improvement of business in June, which fell away again in July, did not in general supply sufficient orders for any length of time. The terrific increases in the prices of raw and semi-manufactured materials, some of which are several times world market prices, the high wages and salaries, the increase by many times of freights, as well as the increase of all other costs, make production costs not only considerably above pre-war rates, but prices considerably above those of the world market. Competitive quotations abroad can only be achieved, therefore, by sacrifices in price and conditions of payment. On the home market, in addition to the general holding back in placing new orders, considerable difficulties were experienced owing to consumers trying to cancel contracts already placed in view of the difficult economic position. The continued traffic barrier between Occupied and Non-Occupied Germany, the rate of exchange, the drain on working capital by the tremendous increase of raw material prices, wages, freights, duties, and the new taxes, and finally the limitation of credit, both in extent and duration, make the prospects of the machine building industry extremely gloomy, and will probably lead in the near future to further restrictions or particularly in the Occupied Territories, to the closing down of works.

CATALOGUES.

Punching and Shearing Machines.—Messrs. Henry Pels and Co., 1, Boymansstraat, Rotterdam, have sent a folder catalogue containing about 20 illustrations of their well-known machines for punching, shearing and similar work.

Spanners.—A priced list of drop-forged engineer's spanners, single and double ended with hardened and finished jaws, and including all sizes from ½ in. to 2 in., is to hand from Messrs. Benjamin Baker (Lye), Limited, Stourbridge.

Laboratory Equipment.—Messrs. A. Gallenkamp and Co., Limited, 21, Sun-street, London, E.C. 2, have sent us a number of interesting lists and catalogues dealing with electric furnaces, electric heating apparatus, glassware and other laboratory supplies.

Electric Gear.—The British Thomson-Houston Company, Limited, Rugby, send a copy of a new edition of their catalogue of oil-immersed circuit breakers of maximum rating, 300 amperes, 3,300 volts, giving full particulars. The matter covered includes accessories and spare parts.

Monel Metal.—A booklet of technical and practical information regarding the properties and methods of working Monel metal has been issued by Messrs. G. and J. Weir, Limited, Cathcart, Glasgow, as a supplement to their previous publications on the subject recently noticed in these columns.

Steam Road Rollers.—A catalogue describing the construction of their steam road rollers, with specifications of the essential parts, is to hand from Messrs. Marshall, Sons and Co., Limited, Gainsborough. Engines, boilers, and framework are constructed to the highest standards of design, materials and workmanship.

Lubricator.—A mechanically-driven lubricator for delivering a regular supply of oil at a number of points is described in a special catalogue received from Messrs. L. Gardner and Sons, Limited, Patricroft, Manchester. A separate sheet of dimensions and technical data accompanies the catalogue.

Steam Fittings.—Excellent descriptions of their reducing valve for steam pressures, and a special control fitting for their single line system of heating on ships, are given in a catalogue received from Messrs. George Clark and Sons (Hull), Limited, Waterhouse-lane, Hull. Both fittings are patented and are made by the firm.

Electric Light Fittings, &c.—An extensive series of reflectors and lanterns ingeniously designed for the proper diffusion of electric light in various industrial and general applications is illustrated in a new catalogue received from Messrs. Verity, Limited, Aston, Birmingham. The same firm have sent us a leaf catalogue of their new direct-current desk fan.

Fencing.—Messrs. A. J. Main and Co., Limited, Possilpark, Glasgow, whose London Office is at Australia House, Strand, W.C. 2, send a catalogue of fencing wire, nets and sheets with the standards, gates and all the various fittings required, and also complete sheds for hay and grain, cattle, &c. A separate priced list accompanies the catalogue.

Electric Wiring.—A new edition of their house-wiring system with twin wires is to hand from British Insulated and Helsby Cables, Limited, of Prescot, Lancashire. Wires, joint boxes, sealing ends, bases, distribution boxes and all necessary fittings are described and illustrated. A useful list is enclosed of other manufactures, of which catalogues will be sent on request.

Gas Lighting.—The British Commercial Gas Association, 30, Grosvenor Gardens, London, S.W. 1, send an 8-page quarto pamphlet (price 6*d.*) describing the advantages of high-pressure gas burned with inverted mantles as compared with low-pressure gas burned with upright mantles. The examples cited are mainly school rooms in which the light has been improved and the cost reduced.

Crankless Engines.—Some supplementary leaves for insertion in the handbook which was mentioned on page 446 of our issue of October 6, 1922, are to hand from Crankless Engines (Australia) Proprietary, Limited, 450, Collins-street, Melbourne, dealing particularly with the adaptation of the engine to the use of petrol or gas fuel, and its application to stationary and automobile work. The engine as designed for working with steam was illustrated and described on page 290 of our 111th volume.

Electric Welding.—A special generator and a complete portable plant, driven by a petrol-paraffin engine, for electric arc welding, are shown in a new edition of catalogue No. 82, received from the Consolidated Pneumatic Tool Company, Limited, 170, Piccadilly, London, W. 1. All accessories, including safeguards for the workmen, are described. The portable plant also includes a compressor for pneumatic tools used in the chipping and grinding necessary with the welding process.

Oil Engines.—The catalogue of oil engines issued by Messrs. Norris, Henty and Gardners, Limited, Patricroft, Manchester, gives very complete and clear illustrations and description of the principal parts of these, in addition to views of completed engines. The range of vertical engines made by the firm are suitable for marine propulsion and marine auxiliary purposes, as well as for general work on land. The table of standard sizes cover a range of 17 powers, from 24 b.h.p. to 200 b.h.p., with two, three or four cylinders and speeds, from 290 r.p.m. to 400 r.p.m. A second catalogue shows horizontal as well as vertica types and smaller powers down to ¾ b.h.p. Full dimension tables and some useful technical data are given.

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